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AMERICAN PHILOSOPHICAL SOCIETY

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THE PROBLEM OF ADAPTATION AS ILLUSTRATED BY THE FUR SEALS OF THE PRIBILOF ISLANDS.

BY GEORGE H. PARKER.

(Read April 23, 1915.)

The breeding habits of the Alaskan fur seals are so unusual as to make these animals unique among mammals. During much of the year, these seals are strictly pelagic roaming over the eastern expanse of the northern Pacific as far southward as the latitude of southern California. As summer approaches, practically the whole herd consisting of several hundreds of thousands of individuals repairs to the two small islands of St. George and St. Paul in Bering Sea for the breeding season. It is the relative proportions of the various constituents of the herd during this breeding period that affords material for interesting speculation.

The movements of the fur seals in their arrival and departure from the Pribilof Islands take place with much regularity. Early in May and June the mature males or bulls, having made their way through the passes of the Aleutians, reach the breeding beaches or rookeries on the islands of St. George and St. Paul. Here they take their positions, fighting all intruders while they await the coming of the females or cows. The cows arrive on the islands chiefly during June and July. They associate themselves with particular bulls and the bull with his group of cows constitutes the family unit or harem. In 1914 the average harem was not far from one bull

to sixty cows, and the range extended from harems containing one cow to some that contained over a hundred. Because of the many years of commercial killing, chiefly directed against the males, it is impossible to state what the size of the normal average harem should be, but probably not far from one bull to thirty or forty cows.

Within a short time after the arrival of the cow, in the harem, *i. e.*, within a few days or a week or so, she gives birth to a single young or pup. So far as is known, cows do not produce more than one pup at a time. Shortly after the birth of her pup, the cow goes into heat, pairs with the bull, and becomes pregnant again. As these are annual occurrences, the period of gestation in the fur seal must be a few days less than a year. The pups are born males and females in about equal numbers. The counts of former years, as well as those of 1914, show a slight predominance of males, the excess being from a little over two per cent. to about seven per cent. of the total births.

The breeding season closes toward the end of July or early in August and this close is marked by the disintegration of the harems. During August most of the bulls begin their migrations back to the Pacific, and the pups, which heretofore have remained on the beaches, begin to take to the sea. They and the cows stay about the islands till November, when they too start on their migration to the open ocean. The only important constituent of the herd that has not yet been mentioned is the class known as the bachelors, *i. e.*, the young males that have not yet attained to breeding. The bachelors move with the cows, arriving for the most part in June and July, and departing in November, though some are found on the islands in December or even later. The bachelors do not mingle on the beaches with the rest of the herd, but gather to one side of the breeding grounds proper in the so-called bachelors hauling grounds, where they lead an idle rollicking existence suggested by their name.

The maximum age of the fur seal is believed to be about twelve to fourteen years for both males and females. In the migration, the males return to the islands approximately in the sequence of their ages; the old bulls arrive first in May and June followed by the younger bulls and bachelors and lastly by the yearling males, which arrive in the latter part of July and in August. The year-

ling males on arrival associate with the pups and cows rather than with the other bachelors. The bachelors may begin breeding at five years of age or even four, but they do not normally undertake this function until they are six or seven years old, when they desert the bachelors' hauling grounds for the breeding rookeries. The period of their normal breeding life covers, therefore, a term of perhaps some seven years or more.

It is not impossible that the yearling females do not return to the islands or, if they do, it is probable that they do so only in small numbers and late in the season. The two-year-old females return to the islands in July and August as virgin females, pair with the younger bulls, and reappear a year later, the end of their third year, with their first pup. From that time on they enter into the regular breeding of the herd and continue in all probability to produce one pup annually. Their breeding life, therefore, extends over some ten or more years.

These in brief are the main facts concerning the breeding habits of the Alaskan fur seal, an animal that exhibits one of the most remarkable examples of concentrated and localized breeding known. When it is recalled that these seals range over thousands of miles in the northern Pacific and that all sexually active members of the species without exception congregate in the appropriate season on the two small islands of St. George and St. Paul for breeding, the very exceptional nature of their reproductive activities must be evident.

The proportion of the two sexes at birth is very nearly equal, yet when the breeding age has been reached, the natural relations are not far from one male to thirty or forty females. As there is no reason to suppose that the death rate is higher in males than in females and as the length of the breeding life of the two sexes is not very different, about seven years for the bulls and about ten for the cows, it follows from the sexual proportions already mentioned, that we should expect an excess of bulls to be present. As a matter of fact, such is the case, for even in 1914, after the excessive commercial killing of males in the past, the so-called idle bulls were much in evidence. It thus appears that the Alaskan fur seal produces at birth approximately equal numbers of males and females

and yet in its breeding activities needs only relatively few males, a condition which when viewed as a whole seems to be a misadjustment rather than a close adaptation to the actual needs of the species. The measure of this misadjustment would be the proportion of idle bulls naturally present. Unfortunately, the commercial activities of the past in exploiting the herd for its fur prevent the possibility of accurate statement on this point, but the presence of idle bulls in the herd today is enough to show that this class under natural conditions would be abundantly represented.

The fur seal, however, is not the only one of the higher animals to show this misadjustment in the ratio of males to females. A prosaic example of the same kind is seen in the barn-yard fowl. Here the sexes hatch in nearly equal numbers, there being perhaps a slight predominance of females, but in maturity the cock holds sway over a flock of hens. This condition is almost exactly parallel with that of the fur seal except that it occurs under domestication. Nevertheless it has probably been inherited from the wild stock, for Finn states that though the red jungle fowl will live quite happily with a single hen, this is not universal and harems are often found. The bull of the American elk or wapiti, as my friend Dr. J. C. Phillips tells me, also forms, during the breeding season, a harem of cows from which he will drive away other bulls of his own kind, much as the fur seals do. Dr. Phillips further informs me that there are among the higher vertebrates many other instance of that particular form of polygamy in which one male during the breeding season naturally associates with many females. Such examples are found among some of the larger antelopes, wild sheep, and wild goats, and among certain birds such as the black grouse, capercaillie, and wild turkey. Although in these several species, the proportions of sexes at birth, so far as I am aware, are not definitely known, they probably follow the rule of approximate equality so common among many of the other higher animals and thus in reality illustrate much the same condition as that seen in the Alaskan fur seal.

Among the lower animals, particularly the insects, exceptional ratios in the sexes have long been known, the classic example of the honey bee being the most commonly quoted. Here a few

males, the drones, are set off against one perfect female, the queen, and a host of imperfect ones, the workers. These cases differ from those in the higher animals, however, in that the sex ratios appropriate for the breeding colony are determined from the beginning, *i. e.*, the young are not produced males and females in equal numbers. Such cases as the honey bee and other like insects exhibit, therefore, in their sex ratios much more accurate adjustments to their breeding requirements than do the higher animals; in fact they may be said to show a very high order of intracolonial sex adaptation.

Throughout the animal kingdom as a whole sexual reproduction seems to be best adjusted where the sexes are represented in approximately equal numbers and this relation is probably determined by the production of equal numbers of male-determining and female-determining sexual elements. The sperm cells of most species of animals, perhaps of all, are apparently the prime factors in this determination, and the dimorphism of these cells in the sense that one class is made up of male-determiners and the other of female-determiners as well as the production of these two classes in equal numbers may be looked upon as the chief adaptation of the animal kingdom so far as sex ratios are concerned. But the reproductive activities of a limited number of animals, such as the honey bee and the fur seal, have developed in directions in which equal numbers of the two sexes serve no longer as an advantageous combination. To meet these new conditions, further adaptation would be needed and, from what has been said, this adaptation would involve readjustments in the powers of the sex-determining reproductive cells. Such readjustments seem to have been carried out in the insects as seen in the honey bee, etc., where through the development of natural parthenogenesis the usual sex ratio has been entirely set aside and a new one favorable to the new requirements has been established. This has not been accomplished by the fur seals and other higher animals which in this respect remain poorly adapted to their new relations. From this standpoint, then, such lower animals as the insects show a higher order of adaptation than either the mammals or the birds. An explanation of this paradox may be found in the fact that the rate at which generation follows generation in in-

sects is enormous compared with that in the higher animals and further that geologically speaking the insects are much older than the mammals or birds. Hence they have had a much greater opportunity to adapt themselves to their conditions than has fallen to the lot of the higher animals. If the maladjustments of the sex ratios as exhibited by the fur seals and other higher animals are to be interpreted in the way indicated, it is clear that the evolutionary processes by which adaptation is brought about must often be slow and imperfect with the result that adaptation itself is better described, in the words of Bateson, as a poor fit than in the extravagant terms of eulogy with which many of the older writers clothed it.

HARVARD UNIVERSITY,
April 23, 1915.

THE LARGE FRUITED AMERICAN OAKS.

By WILLIAM TRELEASE, Sc.D., LL.D.

Plates I–III.

(*Read April 23, 1915.*)

When Alphonse de Candolle monographed the oaks of the world something over a generation ago,[1] he distinguished with a varietal name a form of our common white oak with small acorns some 8 × 14 mm., which Engelmann had sent him—the usual fruit of *Quercus alba* measuring about 14 × 18 mm. Those who have examined numerous specimens of our common red oak, *Q. rubra,* and its double, *Q. Schneckii,* have noted that they occur in forms varying in diameter of the acorn from about 10 to about 20 mm. The assemblage of forms clustering about the Californian *Q. chrysolepis,* the oldest of our existing types of oak, geologically, also show a comparable or even greater difference in the size of the fruit of what are otherwise held to be mere variants of a single species; and the polymorphic *Q. dumosa* presents a similar if less extended range of fruit size.[2]

The most surprising of our species in this respect is the bur oak, which joins to its great range in size a difference in fruit which is even more startling; for while the usual diameter of the acorns of this species is somewhere about 25 mm., and of the cup five or ten millimeters more, the acorns frequently measure 40 mm. in diameter with a cup fully 50 mm. across on the one hand, while on the other hand they may scarcely reach a diameter of 10 mm. Perhaps no oak presents so great a range of cup characters as this species does.[2] While the round or ovoid scaly-fringed form covering the acorn nearly or quite to its top is taken as the most typical and has given to the tree its common name of mossy or overcup oak, it is not un-

[1] *Quercus alba microcarpa* A. de Candolle, Prodromus, 16^2 22. 1864.

[2] On these consult Sargent, Silva, vol. 8.

common to find a broad saucer-shape assumed with the fringe of slender scales either seemingly absent, because closely inflexed beside the acorn, or extended in its development over a considerable part of the outside of the cup; and it is even possible, as Professor Pieters has recently shown me by material collected about Ann Arbor, for the cup of the smaller type of fruit to be shallow and thin as in the post oak, and either delicately ciliate at top or entirely without a fringe even on a single tree.

Even the largest acorns produced by these or our other familiar oaks seem small when compared with those of some tropical species of *Quercus,* or of the related genus *Pasania.* On our own continent, where the true oaks extend from the far north into the high Andes of Colombia, these large-fruited species are of both the red— and white-oak groups,—the former in Guatemala and Chiapas, and the latter in the last-named state of Mexico and along the flanks of the eastern Sierre Madre range above Vera Cruz. In contrast with these, which may reach a diameter of 50 or even 60 mm., the smallest acorns, also Guatemalan and Mexican, and of the group of red oaks, scarcely measure 5 mm. in diameter.[3]

Some two years ago, while looking over a series of type photographs that I had made in the course of a systematic revision of the oaks of tropical America, Mr. Walter Swingle, of the National Department of Agriculture, expressed considerable interest in some of the east-Mexican large-fruited white oaks as affording a hopeful field for experimentation both in direct propagation and hybridization, with reference to our own tropical and subtropical regions, and Mr. David Fairchild, of the same government department, considered the matter of sufficient interest to undertake importations through the interest of Dr. C. A. Purpus, whose collections in the southern republic have done much of recent years to make its vegetable wealth known. The purpose of the present communica-

[3] *Quercus parviglans* n. nom.—*Q. microcarpa* Liebmann, Overs. Dansk. Vidensk. Selsk. Forhandl. 1854: 184.—Liebmann-Oersted, Chênes Amer. Trop. 26. *pl. 6.*—Not *Q. microcarpa* Lapeyrouse, Hist. Abr. Pl. Pyren. 582. 1813. Equally small are the racemed acorns of an as yet unpublished group of west- and south-Mexican species of the red oaks; and the east-Mexican white oak, *Q. glabrescens*, possesses an equally small-fruited variety.

tion is to give a connected account of these large-fruited species, because of this popular interest that they possess.

The first of the large-fruited tropical American species to be made known is *Quercus Skinneri*[4] collected by Hartweg at Quezaltenango, Guatemala, which Bentham noted and illustrated in 1841 and described the following year. Skinner's oak is a large tree with long-petioled, ovate, acute, rather blunt-based aristately toothed glabrous leaves about 5×9 cm., producing solitary or paired short-stalked fruit resembling that of our common red oak but on a much larger scale, the shallow cup 50 mm. in diameter and the short-ovoid acorn of about that length. It is a red oak with the usual characters of apical abortive ovules and tomentose interior of the shell, but the latter is thicker than usual and with the septa intruded into the kernel so as to make the latter somewhat three-lobed. Of recent years *Q. Skinneri* has been collected only by Cook and Griggs, at the Finca Sepacuite, Guatemala. A similar, if not the same, red oak, but with larger duller winter buds and lance-elliptical leaves as much as 20 cm. long, was collected at Chinantla, in the Mexican State of Oaxaca, by Liebmann in the fall of 1842, but of it nothing else is known: as with *Furcræa longæva,* the species seems to range extensively through the Cordillera.

Closely related to Skinner's oak is a species recently collected by Dr. Purpus in the Mexican state of Chiapas, the similar acorns of which may reach a diameter of over 35 mm., their very shallow cups, with thickened scales, sometimes measuring 45 mm. across. This, which differs markedly from *Quercus Skinneri* in having acutely lanceolate very short-stalked leaves about 5×12 cm., may be called *Q. chiapasensis*.[5] Like the other oaks here under consideration, it appears to become a tree of very large size.

The year following the full description of *Quercus Skinneri,* the Belgian botanists Martens and Galeotti described under the name

[4] *Quercus Skinneri* Bentham, Gard. Chron. 1841: 16. *f.*; Pl. Hartweg. 90. 1842.—Hooker, Icones Plant. 5. *pl. 402.*—Liebmann-Oersted, *l. c. pl. B, 3.*

[5] *Quercus chiapasensis* n. sp. Arbor grandis: foliis brevipetiolatis, acutis, lanceolatis, aristato-dentatis; fructu magna; cupula plana, glabra, crassa; glande semiglobosa, 35 mm. diametro. *Q. Skinneri* affinis.

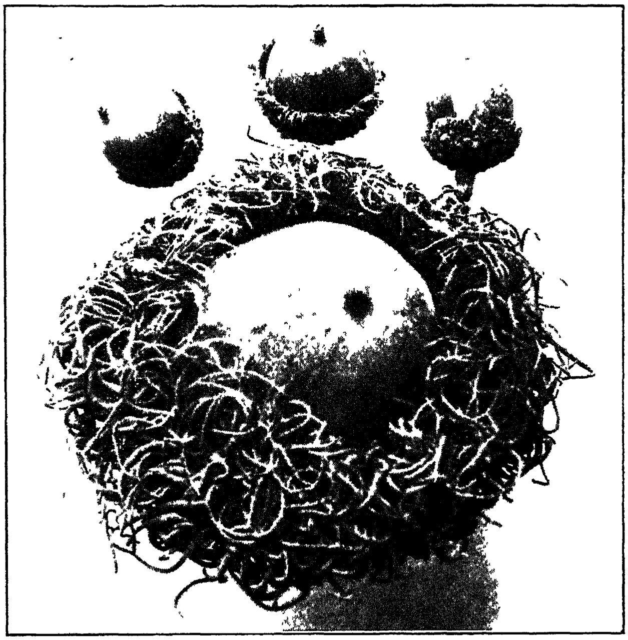
Q. insignis[6] what must be regarded as most notable in its genus because of the enormous height of the trees and the production of acorns occasionally fully 60 mm. in diameter and thus out of comparison with those of any black oaks and even with those of such Asiatic Pasanias as *P. cornea*. *Quercus insignis*, which occurs along the upper flanks of Mount Orizaba in eastern Mexico, is a white-oak, with the interior of the acorn shell not woolly, and with deeply lateral ovules. Its short-petioled elliptical-oblanceolate more or less acuminate leaves are sharply low-serrate but without bristle-like tips to the teeth, and measure 5×10 cm. or more. The fruit, which matures the first season, as seems to be true of all white oaks, is typically biscuit-shaped and about one-fourth shorter than thick, and the rather shallow cup, which may reach 80 mm. in diameter, is covered with coarse heavy loosely ascending scales.

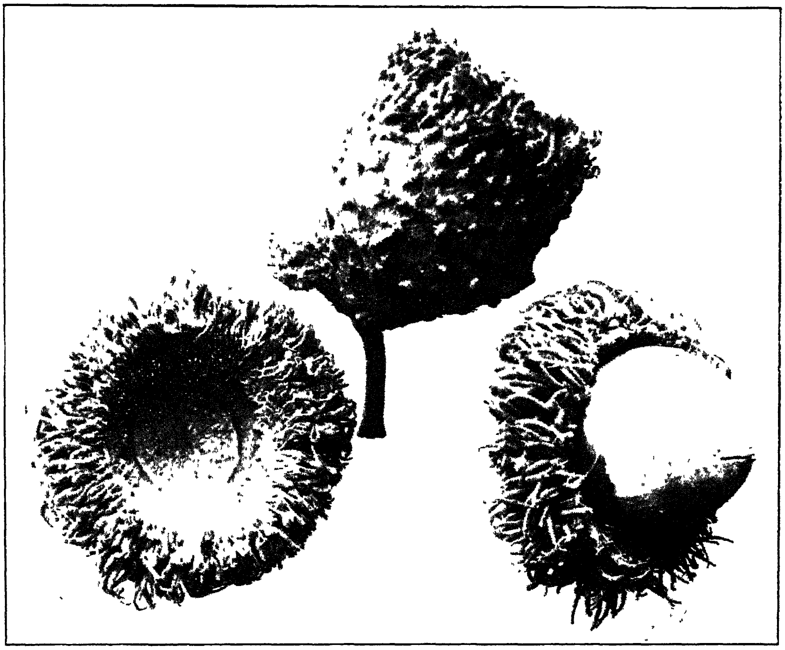
Martens and Galeotti do not appear to have seen more than one form in the oaks of this kind; but the type collection of Galeotti as represented in the museum at Budapest contains acorns of two sorts, one depressed, and the other acuminately conical and about as long as thick. At about the same time that Galeotti's collections were made, the Danish botanist Liebmann collected in the same general region materials of an oak similar to *Q. insignis* but differing in bearing subconical acorns about as long as broad and with more turbinate cups. This was published by its discoverer in 1854 under the name *Q. strombocarpa*.[7] Subsequently when a series of exquisite drawings of Mexican oaks prepared under Liebmann's direction were published by Oersted, the latter added a plate of a very similar form, which he called *Q. insignis strombocarpoides*.[8] It is hard to see how the latter can be distinguished from *Q. strombocarpa*, and the Galeotti collection shows that, different as the fruit extremes are, the discoverer of *Q. insignis* did not separate from its typical form the conical-fruited form to which apparently both of the later names refer.

[6] *Quercus insignis* Martens and Galeotti, Bull. Acad. Brux. 10^2: 219. 1843.—Liebmann-Oersted, *l. c. pl. K, 29.*

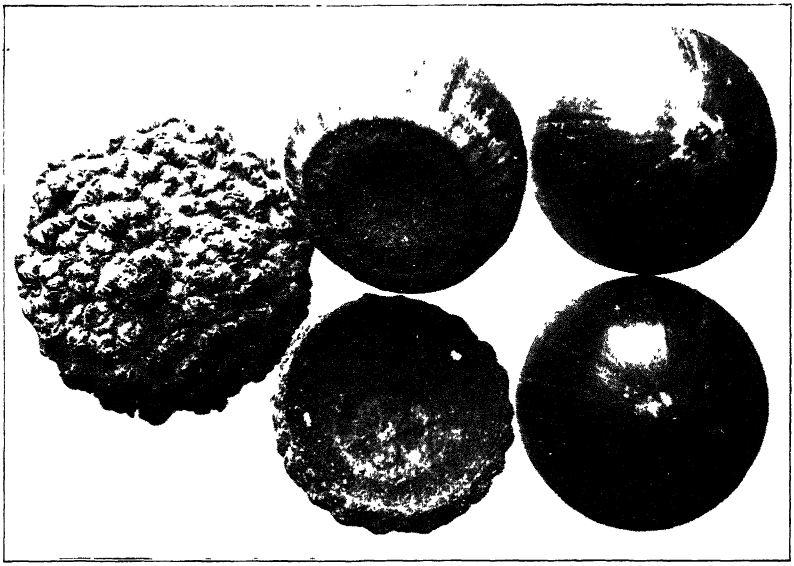
[7] *Quercus strombocarpa* Liebmann, Overs. Dansk. Vidensk. Selsk. Forhandl. 1854: 176.—Liebmann-Oersted, *l. c.* 24. *pl. 27.*—Oersted, Bidrag Kundsk. Egefamilien. 346. *f. E.*

[8] *Q. insignis strombocarpoides* Liebmann-Oersted, *l. c. pl. 28.*

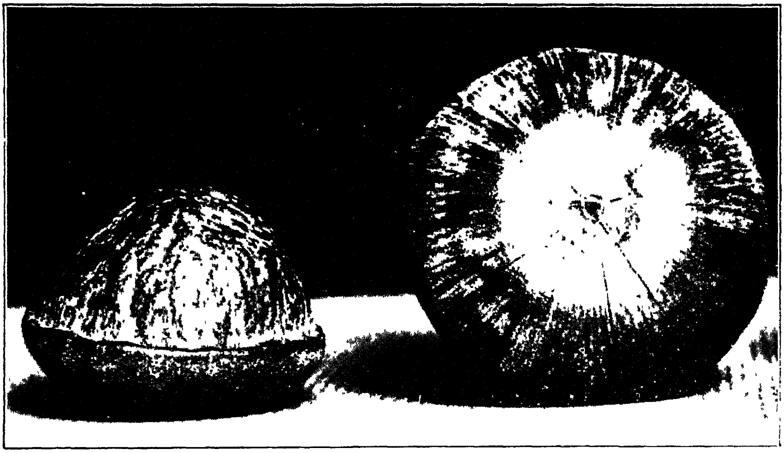




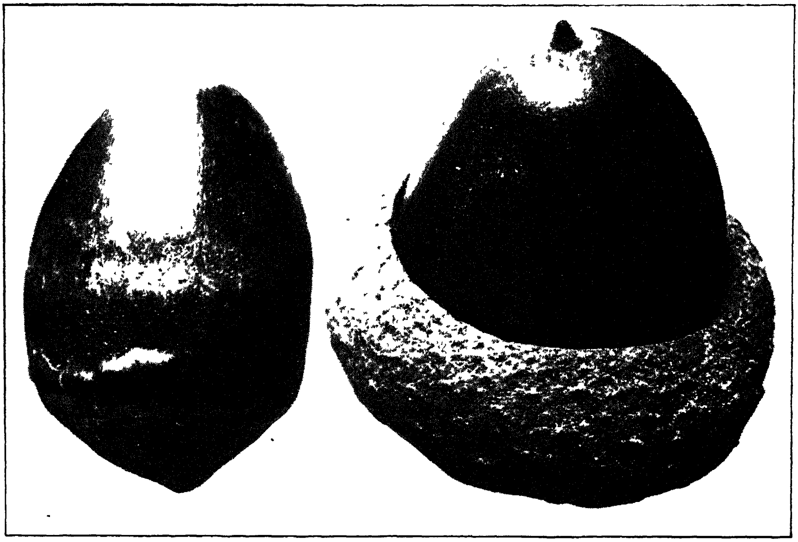
QUERCUS MACROCARPA.



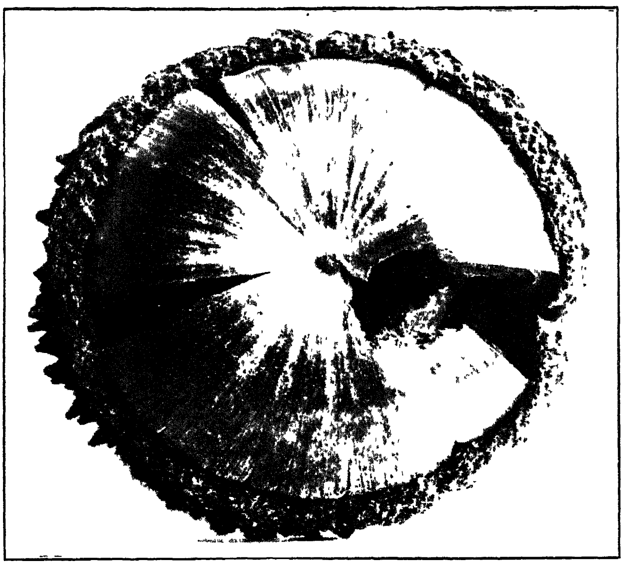
QUERCUS CHIAPASENSIS.



PASANIA CORNEA.



QUERCUS CYCLOBALANOIDES.



QUERCUS INSIGNIS.

Wishing materials that should throw light on this question, I turned in 1912 to my amiable correspondent, Dr. Purpus, who was then in eastern Mexico: but before my letter reached him, Dr. Purpus had gone into southern Mexico. The result of my appeal, therefore, was not further specimens of *Quercus insignis,* but collections of an equally large and almost equally large-fruited white oak which appears to be characteristic of the Chiapas region. With somewhat similar but more deeply toothed leaves about 7×20 cm., equally short-petioled, this combines a stoutly stalked turbinate cup as much as 60 mm. in diameter, the scales of which are barely if at all free at tip with their bases connate in zones; and the ovoid pointed acorn measures $40–50 \times 50–60$ mm. Though closely related to *Q. insignis,* this species is so distinct in its collective characters as to stand as the type of a separable group of white oaks, and it has been called *Q. cyclobalanoides*[9] because of its very peculiar cup-markings.

EXPLANATION OF PLATES.

(All figures are of natural size.)

Plate I.

Quercus macrocarpa. Above, three acorns from a very small-fruited Michigan tree (*Pieters*), partly with and partly without fringe to the cup, and a single fruit of the largest and "mossiest" type from Illinois (*Adams*). Below, two of the more typical acorns of different cup-depth, and a cup showing a not infrequent inrolling of the inner scales, also from Illinois (*Adams*).

Plate II.

Above, two cups and three acorns of the large-fruited Mexican red oak, *Quercus chiapasensis* (*Purpus*). Below, basal and side view of two acorns of the large-fruited Chinese oak, *Pasania cornea* (after photographs by Fairchild).

Plate III.

Above, two fruits of the Mexican ring-scaled white oak, *Quercus cyclobalanoides* (Chiapas, *Purpus*). Below, a fruit of the great-acorned Mexican white oak, *Quercus insignis* (Huatusco, *Purpus*).

The University of Illinois,
March 8, 1915.

[9] *Quercus cyclobalanoides* n. sp. Arbor grandis; foliis brevipetiolatis, acutis, oblanceolatis, mucronato-dentatis: fructu magna; cupula turbinata, luteo-tomentosa, pluriannulata; glande ellipsoidea, sub 50 mm. diametro. *Quercus* Insignes valde affinis, sed sectio distincta, Cyclobalanoideæ, constituens.—*Q. insignis* Journal of Heredity, 5: 407. *f. 12.* 1914—not Martens and Galleotti, *l. c.*

THE SWEDES, GOVERNOR PRINTZ AND THE BEGINNING OF PENNSYLVANIA.

By THOMAS WILLING BALCH.

(*Read March 5, 1915.*)

Of the original thirteen States, those south of the Middle States as well as those known under the collective name of New England, were settled by men and women of English race. New York, New Jersey and Delaware were first settled by Hollanders. The whole area of the Dutch settlements was known as New Netherland, and the chief city of the Hollanders in the new world was called Amsterdam in New Netherland, though historians afterwards thought fit to change the name into *New* Amsterdam,[1] doubtless because the English had renamed the town *New* York. The settlements in the valley of the Hudson and in what is now New Jersey passed by conquest into the hands of the English. The Dutch settlement in Delaware was destroyed after six months by the Indians. Subsequently, the Swedes took over the inchoate title of the Dutch to present-day Delaware. The Swedes later lost Delaware to the Dutch by conquest, who in their turn were afterwards conquered by the English.

No European Power, however, occupied and took possession of what today constitutes the Commonwealth of Pennsylvania, until Lieutenant-Colonel John Printz, who was the fourth Governor of New Sweden,. moved up from Delaware to Great Tinicum Island and there established, in 1643, his seat of government, the first capital placed in the territory of the present State of Pennsylvania. He thereby became the first governor of the territory now known as Pennsylvania.

That Sweden was the first European nation to possess itself of what is present-day Pennsylvania was supported by the International

[1] I have to thank Mr. Robert H. Kelby, the learned librarian of the New York Historical Society, for this information.

Law of the seventeenth century. Towards the end of the sixteenth century there grew up as a rule of international law that, in order that a member of the family of nations could claim as its own a newly discovered and virgin land, it was necessary for that nation to actually occupy and possess that virgin land. The act of merely discovering and christening such an unoccupied land did not give the right of possession. The act of possession must be an actual occupancy through the establishment of forts and settlements in that land. Queen Elizabeth enunciated this principle clearly in 1580 in a notable answer she made at her court to the Spanish Ambassador, Mendoza.[2] It was thus recognized by England through the lips of her sovereign, a sovereign who well knew how to maintain the dignity and interests of her realm abroad. That rule became more and more recognized both by the publicists in their writings and by the nations in their acts, and has remained a rule of international law until the present day.

The sovereignty of Sweden over the land now known as Pennsylvania passed later by conquest to the States General of the United Netherlands, and subsequently again by conquest to the British crown, by whom it was afterwards granted to William Penn.

The fact that the sovereignty of Pennsylvania, alone of the original thirteen, goes back to Sweden for its beginning and that Printz was the first in the line of its governors, is known to only a very few. It would seem well then, that proper monuments to Printz and his Swedish settlement should be erected, so that future generations may know of the beginning of this province and state. And no place would seem more appropriate than the ancient hall of this venerable society of learning, the oldest existing society of learning not only within the bounds of Pennsylvania but also in all of the new world as well, to suggest that, first a bronze tablet should be erected in memory of Governor Printz and his capital called Nya Göteborg on Great Tinicum Island; and second, a bronze statue of Governor Printz, either of life or heroic size, should be placed at some conspicuous place in the city of Philadelphia.

[2] Camden's "Annals," 1580; see translation in Sir Travers Twiss's "Oregon Question."

GENERAL RESULTS OF THE WORK IN ATMOSPHERIC ELECTRICITY ABOARD THE CARNEGIE, 1909–1914.

By L. A. BAUER.

(*Read April 24, 1915.*)

Notable progress, it is believed, has been achieved by the department of terrestrial magnetism of the Carnegie Institution of Washington during the past year in the perfection of the instrumental appliances for observations in atmospheric electricity. In various articles by Drs. Swann and Hewlett, which have appeared in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*, 1913–1914, new points of theory were brought out, serious errors in certain instruments were made known, and improved methods and instruments were devised. As a result considerable improvement has been made in the work in atmospheric electricity aboard the *Carnegie*, especially on her present cruise.

It is now deemed worth while to expand the work of the department in atmospheric electricity in two directions: (*a*) Continuous observations, by self-recording means, at the department's laboratory in Washington and at such observatories elsewhere as the department may be able to establish in the near future. (*b*) A general electric survey of the globe, implying observations at points distributed over the earth's surface, somewhat as in a magnetic survey.

Probably the late Professor Rowland was one of the first, in his address before the Congress of Electricians, held at Paris, September, 1881, to point out the need in atmospheric electricity "of a series of general and accurate experiments performed simultaneously on a portion of the earth's surface as extended as possible."[1] He says that "the principal aim of scientific investigation is to be able to understand more completely the laws of nature, and we generally succeed in doing this by bringing together observation and theory."

[1] Physical Papers of Henry A. Rowland, Baltimore, 1902, p 212 et seq.

On Professor Rowland's motion the Congress resolved "that an international commission be charged with determining the precise methods of observation for atmospheric electricity, in order to generalize this study on the surface of the globe."

Unfortunately, in the past, the observations in atmospheric electricity have often been found to be counterfeits of nature because of the errors inherent in the instruments and methods used. Accordingly the much-desired discovery of nature's laws by "bringing together observation and theory" has not been effected in the measure desired. None of the proposals for a general electric survey of the earth which have been made repeatedly to learned academies, one of the last having been presented to the International Association of Academies, has been put into effect, doubtless because of the discouraging experiences encountered.

In spite of the vast work already done by notable investigators, we still have no generally accepted theory of the origin of atmospheric electricity.

Probably one of the most important of recent contributions to the observational data is the series of observations obtained on the past cruises of the *Galilee* and the *Carnegie*. A report giving the results up to the end of 1913, obtained by the department observers and others, was prepared by Dr. Hewlett and published in the September, 1914, issue of *Terrestrial Magnetism and Atmospheric Electricity*. The observations comprised, in addition to the usual meteorological measurements, those of the potential gradient, atmospheric conductivity and radioactive content of the atmosphere. Perhaps the most important result was a confirmation of the somewhat striking phenomenon, that while the conductivity over the ocean is, on the average, at least as great as over land, the radioactive content is much smaller. The values of the potential gradient obtained at sea were of the same order of magnitude as those on land.

Dr. Swann has just completed a report on the atmospheric-electric observations taken during the third cruise of the *Carnegie* while under the command of Mr. J. T. Ault, in 1914. The general course of the *Carnegie* during this cruise was as follows: Leaving Brooklyn on June 8, 1914, she arrived at Hammerfest on July 3.

Sailing again from Hammerfest on July 25 she entered the harbor of Reykjavik, Iceland, on August 24, having reached the latitude of 79° 52′ North, off the northwest coast of Spitzbergen. Leaving Reykjavik on September 15, the *Carnegie* arrived at Greenport, Long Island, on October 12, returning to Brooklyn on October 21, 1914.

The observations in 1914, comprised, in addition to the magnetic and meterological data, measurements of the potential-gradient, the conductivities for the positive and negative ions, and the radioactive content. Measurements of the ionic numbers were also made during the passage from Greenport, through Long Island Sound to New York. The whole of the observations, with the exception of a few measurements in Long Island Sound by Dr. Swann, were taken by Observer H. F. Johnston.

The average values of the potential-gradient, atmospheric conductivity, and radioactive content for the whole cruise were, respectively, 93 volts per meter, 2.52×10^{-4} E. S. U., and 23, the last number being expressed in Elster and Geitel units. The average value of the earth-air current for the whole cruise was 7.7×10^{-7} E. S. U. per sq. cm.

The atmospheric-electric elements were measured daily between the hours of 9 A. M. and 12 noon. The observations as far as they go indicate a general increase of the potential-gradient from summer to winter, which is in accord with land observations for the daily mean values. The conductivity also shows a general increase from the beginning of the cruise (June 8, 1914) to about the end of September, when a maximum occurs, after which the conductivity falls.

No marked variation of the atmospheric-electric elements with temperature or humidity was found. However, an indication is shown of a variation of the conductivity with latitude; a maximum for the latitudes involved occurring in the neighborhood of 50° North. These conclusions with regard to the variation of the elements with season, latitude, etc., must be looked upon as tentative owing to the small number of data involved.

The conductivity appears to have an especially low value in the neighborhood of the American coast. In Long Island Sound,

measurements were made of the ionic numbers n_+ and n_-, and the results indicate that the low values of the conductivity referred to above are to be attributed partly to a low value of the specific velocities of the ions (v_+ and v_-). The mean values of v_+ and v_- for observations on three days in Long Island Sound are respectively 0.77 and 0.83 cm./sec. per volt per cm. The average value of n_+ and n_- for observations taken on three days in Long Island Sound are 340 and 280 ions per c.c. respectively.

By making use of the value (23) given above for the radioactive content, and of the empirical relation obtained by Kurz, for the reduction of the Elster and Geitel unit to absolute value, it turns out that the average radioactive content for the whole cruise amounts to about 12 curies of radium emanation per cubic meter as against 80 curies per cubic meter which is about the average value found over land. The emanation content is thus too small to account for the conductivity observed over the sea, which conductivity is as great or greater than that measured over land.

A criticism of the ordinary method of drawing conclusions as to the nature of the radioactive products in the atmosphere, by comparing the decay curve with one obtained by a wire exposed in a closed vessel, is given in Dr. Swann's report. The activity curves are analyzed in the report mathematically, use being made of the theory of radioactive disintegration, and it is found that while some of the curves can be explained by radium emanation alone, others require the presence of a product of longer decay period than radium *A, B* or *C*. The possibility of this extra product being a product of thorium emanation, as is generally assumed to be the case on land, is discussed by Dr. Swann.

An attempt to calculate the actual amount of radium emanation in the air directly from the theory of the Elster and Geitel method, without assuming any empirical relation results in a much smaller value for the radium-emanation content than that given by the empirical relation unless it is assumed that the average specific velocities of the active carriers are much smaller than is generally supposed.

THE RIGHTS AND DUTIES OF NEUTRALIZED TERRITORY.

By CHARLEMAGNE TOWER.

(*Read April 23, 1915.*)

Although the growing importance of the United States and their extended influence as a world power have made the subject one of prime interest to them in many respects heretofore, there has probably never been a time when the principle of neutrality has had for us in America the same weighty consideration that it has under the existing circumstances in the world today.

Never, probably, have the rights and duties of neutrals been so carefully scrutinized by American public opinion, or so sensitively tested by the responsible authorities of our Government. And very justly so, because, with almost the whole of Europe inflamed before us in this great war, there is scarcely a day in which some serious question does not present itself in the maintenance of our public policy, some delicate situation which affects our national honor,—both in our character of neutrals and our relations with the belligerent powers, and in their dealings with us in return.

It may be of interest, therefore, to consider one or two of the underlying principles of the rights and duties of neutral nations; not the less so, perhaps, because of the fact that neutrality, in its present recognized form, is the most recent and most modern of the effective rules of international law.

Indeed, the nations of antiquity had not only no conception of what we call neutrality, but they had not even a name by which to convey our meaning of the term. The Romans alluded to those not engaged in the war as *medii, amici* or *pacati;* and their dealings with them were regulated, as far as we can judge, by the feeling that they were peaceful and friendly; at all events that they were not openly to be regarded as the enemy. And this appears to have been the view of their position throughout the Middle Ages. It

was only in the seventeenth century that the term *neutralis*,—meaning to the minds of the people of that day, *non hostis*,—was brought into general use by the publicists, and that since then the condition of the neutral has been established, somewhat artificially, as is considered by some writers,[1] under the process of which the term *neutral* has been extended to the flag of a nation which chooses to take no part in the war, to its ships, its commerce and its citizens.

From this point of view it has been declared that neutrality is "the continuation of a previously existing state." That is to say: Powers which go to war and become belligerents alter their condition,—whilst those which choose to be neutral remain as they were before. Consequently, in their case, their international rights are unchanged; and "neutral states and their citizens are free to do in time of war between other states what they were free to do in time of peace."[2]

But, under the rules of international law, the state of neutrality carries with it certain rights and obligations which do not exist when there is no war. It has been settled that neutral governments may regulate the furnishing of certain articles to belligerent cruisers that seek hospitality in their ports, though they are bound to prohibit the supply of certain other articles, as, for instance, arms and ammunition. They have the right to enforce the respect for the neutrality of their waters, though they must not allow their territory to be used for fitting out or equipping armed expeditions against any belligerent. So also, the commerce of neutral individuals is subject to certain restrictions, as, in the matter of contraband of war, which do not exist in time of peace.

But the theory of the law is that these are merely the changes in certain details produced by common consent of the nations,—by the condition of war; though the principle remains permanently fixed, that the rights of a neutral continue, uninterrupted, in time of war precisely as in time of peace,—his rights of trade and commerce, his rights of free intercourse with either belligerent, or with anyone else; and that every restriction upon these activities that

[1] Holland, *Fortnightly Review*, July, 1883.

[2] Lawrence, "International Law," par. 243.

are lawful in a state of general peace must be based upon a clear and unquestioned rule of international law; the burden of proof being upon him who seeks to enforce the restraint.

As a general statement, the obligations of all neutral states are the same, so also are their rights, as non-belligerents and non-participants in the war; they decide by their own motion to occupy a neutral position, aside from and between the belligerents, with all of whom they voluntarily remain at peace. This is called "perfect neutrality," and is accepted by all the powers. But there are two classes of neutrals into which the whole body of neutral nations is divided, whose relations to the war are different in this respect: that, one set of them abstain by their own free will from entering the war; whilst the others are restrained from taking part in the hostilities and are obliged to remain out of it by the conditions of their existence. This difference between them marks the difference between neutrality and neutralization; between neutral and neutralized territory. And it is to this latter that I beg leave for a moment to direct attention.

A neutralized state, then, is one which is and must remain neutral under all circumstances. Its independent existence rests upon that condition. It is a state which has been constituted by common consent of the great powers, which has received from the powers the right to subsist, provided that it take no part whatever in any conflict that may arise between its neighbors and shall have no right of its own to take up arms except to repel attack or to defend its territory. Thus a neutralized state is, in fact, allowed to exist because the operative forces of self-interest of its neighbors find sufficient benefit accruing to themselves,—as, for instance, that it forms an intervening space between themselves and their own powerful neighbors whose proximity threatens their peace,—to induce them to agree to its existence. There are neutralized states, under international law, and neutralized individuals; and this character may be extended also to seas and waterways, to buildings, ambulances and ships.

A distinguished authority (Professor Holland) defines the process of neutralization as "the bestowing by convention of a neutral character upon states, persons and things which might otherwise

bear a belligerent character." But, "so great a change in their legal position cannot be made without the consent of all the parties affected by it. It must be made as the result of international agreement, in order to be valid, and must be accepted by all the important states."[3]

Neutralized states, therefore, are those which, whilst remaining politically independent, have yielded up a part of their sovereignty as the price of their existence, and are dependent upon the powers to protect them,—though they do not belong to the councils of the great powers, nor have they the right to discuss questions of policy which may ultimately lead to the employment of force, except in defence of their own frontiers.

The two conspicuous examples of this kind are Switzerland and Belgium. The cases are similar; each forms with its intervening territory a barrier between the threatened conflicts of powerful neighbors. Switzerland, lying as it does, between Germany, Italy and France, is so situated that if the passage through its territory were open, the Austrians might proceed freely from the valley of the Danube to the Rhone and the Po, and menace the western boundary of France throughout its entire length; and, indeed, that is what happened during the French Revolution, when the neutrality of Switzerland was disregarded and her territory invaded by all the contending parties, whilst the French, Austrians and Russians used her soil for their hostilities against each other. Again, in 1813, the Austrian army passed through Switzerland and crossed the Rhine at three places, in its campaign against France.

A short time later, the perpetual neutrality of Switzerland was recognized by the Congress of Vienna, in 1815; but, upon the return of Napoleon from Elba, the Allies called upon the Swiss Confederation to join in the general coalition against France, in order to assist them in promoting the common welfare of Europe and prevent the reestablishment of the revolutionary authority in France. They declared that they knew the importance attached by Switzerland to the maintenance of the principle of her authority, and that they did not intend to violate that principle; but with the view of accelerating the time when it might be made permanent

[3] Lawrence, ubi supra, paragr. 245.

and advantageous, they called upon the Swiss to assume an attitude and to take such measures as might be in proportion to the extraordinary circumstances of the moment, without forming a rule in this respect for the future. That is to say, the allied forces claimed the right to pass through Switzerland, recognizing her neutrality but agreeing that if it were violated by them they should not regard their act as a rule in the future. In truth, her neutrality was violated during the war by the contending parties on both sides.

But, after the reëstablishment of the general peace in Europe, a declaration was finally made, at Paris, in 1815, which fixed the political status of the Swiss Confederation, and upon that foundation it has rested ever since. By that declaration, both France on the one side and the allies on the other, Great Britain, Austria, Prussia and Russia, formally recognized the perpetual neutrality of Switzerland and guaranteed the integrity and inviolability of her territory. They declared also that the neutrality of Switzerland, and her independence of all foreign influence, were conformable to the true interests of the policy of all Europe.

The situation of Belgium renders it in this respect similar geographically to that of Switzerland; for it is the barrier which lies interposed between Holland and Germany on the one side and France on the other, and by means of its territory the boundary lines of these great powers are separated from each other in such a manner as to remove the menace of irritation which is always present in Europe where the common frontier is marked by a single line. With this barrier maintained, also, both France and Germany are protected from immediate attack at several of the most vulnerable points in the territory of each; as has been made evident by the conflicts that have taken place between the rival powers on the continent for hundreds of years, which have made Flanders and the low countries the battleground of Europe.

The territory of the present kingdom of Belgium was incorporated with that of Holland, in 1815, by the Congress of Vienna, in order to form the kingdom of the Netherlands, and for the distinct purpose of placing a barrier between the territories of Germany and France. But, quarrels of a domestic character having

broken out in the low countries, Belgium separated itself from the kingdom of the Netherlands, in 1831, the outcome of which was that a treaty was made, on the 19th of April, 1839, establishing peace between Belgium, as an independent kingdom, and Holland; and, on the same date, in 1839, another treaty was entered into by Great Britain, Austria, France, Prussia and Russia with the king of the Netherlands, recognizing that the union between Holland and Belgium, in virtue of the Treaty of 1815, is dissolved, and that Belgium, which is to be composed of certain provinces specifically delimited and set forth, shall become an independent state.[4]

This, then, is the origin and constitution of the kingdom of Belgium as we know it today. The powers agreed that, within certain boundary lines, it should be allowed to exist as a separate kingdom. They went further than that, and agreed also, by Article VII. of that Treaty, that:

We have in this a well-defined example of neutralized territory, as we are considering it today. Belgium was granted all the privileges of independence, with the right to make her own laws, regulate her own domestic affairs and administer her own government; always provided, however, that she should maintain, in her foreign relations, the strictest neutrality toward all other states. And this, it is believed, she has faithfully performed.

But, it will be observed that, whilst Belgium is thus bound to the great powers as to her neutrality, there is no agreement for specific performance upon their part in this respect, beyond their ratification of the convention itself and their general undertaking to carry out all of its provisions, in which the powers themselves had not entire confidence. It was evidently not regarded by them as a sufficient safeguard in the event of war, for when Germany and France declared war upon each other, in 1870, there was such grave danger that both the independence and the neutrality of Belgium would be disregarded in the course of the conflict, that it was considered necessary to assure her safety by special agreement having regard to the circumstances of that time.

[4] Hertslet, "The Map of Europe by Treaty," II., p. 984.

"Belgium, within the limits specified, shall form an independent and perpetually neutral state. It shall be bound to observe such neutrality towards all other states."

Therefore, Great Britain entered into a separate treaty with Prussia, in August, 1870, by which it was agreed that:[5]

> "If during the hostilities the armies of France should violate the neutrality of Belgium, Great Britain would be prepared to coöperate with Prussia for the defence of the same in such manner as may be mutually agreed upon, employing for that purpose her naval and military forces to insure its observance, and to maintain, in conjunction with Prussia, the independence and neutrality of Belgium."

And Great Britain entered into a separate treaty with France, at the same time, making provision in the same terms for the coöperation with her for the defence of Belgium in case that Belgian territory should be invaded by the armies of Prussia. These separate treaties were made binding in each case upon the parties during the continuance of the War of 1870, and for twelve months after the ratification of the treaty of peace. Thus Belgium was protected against invasion or disturbance during the Franco-Prussian War; though since that time both her independence and her neutrality depend upon the old agreement between the five powers, made in 1839.

But, as an old French writer has well said: "With such neighbors there is always a chance for trouble." The unfortunate situation of Belgium leaves her always open to danger when her powerful neighbors begin to fight over her head. She has her defence in the old agreement of the powers, it is true. But will that be a sufficient defence when either or all of the powers, engaged in a desperate conflict amongst themselves, find that their own self-interest, then of prime importance to each of them, places the consideration of Belgium in the background? Evidently not; and in this respect all the powers appear to be alike.

For instance, Sir Edward Grey in his great speech in Parliament, on the 3d of August, 1914, whilst advocating the neutrality of Belgium in the present war, pointed to the *interests* of Great Britain as the determining factor in the observance of the guarantee entered into by the powers, in 1839.[6] He quoted to the House the speech which Mr. Gladstone had made in Parliament, upon the same subject, in 1870, when he said, in regard to Belgian neutrality:

[5] Hertslet, "Map of Europe," III., p. 1886.

[6] *The Times,* London, August 4, 1914.

"There is, I admit, an obligation of the treaty. It is not necessary, nor would time permit me to enter into the complicated question of the nature of the obligation under that treaty. But I am not able to subscribe to the doctrine of those who have held in this House what plainly amounts to the assertion that the simple fact of the existence of a guarantee is binding on every party to-day irrespectively altogether of the particular position in which it may find itself at the time when the occasion for acting on the guarantee arises. The great authorities upon foreign policy to whom I have been accustomed to listen, such as Lord Aberdeen and Lord Palmerston, never to my knowledge took that rigid, and if I may venture to say so, that impracticable view of the guarantee. The circumstance that there is already an existing guarantee in force is, of necessity, an important fact, and a weighty element in the case to which we are bound to give full and ample consideration."

Sir Edward Grey added to this his own statement, that:

"The treaty is an old treaty—1839. It is one of those treaties which are founded not only on consideration for Belgium which benefits under the treaty, but in the interests of those who guarantee the neutrality of Belgium."

Unfortunately this is true. That treaty is evidently an obligation of convenience. Germany, upon her side, took the same view. The German Chancellor in his speech before the German Parliament alluded in this connection to "the wrong which we were doing in marching through Belgium." The German government declared that "it had in view no act of hostility against Belgium." It expected the Belgians to maintain an attitude of friendly neutrality toward Germany,—in return for which it undertook, at the conclusion of peace, to guarantee the independence of the Belgian kingdom in full. The Chancellor hoped that the Belgian authorities would yield to the inevitable and "retire to Antwerp under protest."

I do not intend to pursue this inquiry in the direction in which it has given rise to the controversy on both sides, and possibly the world over, as to whether the Allies were ready to pass through Belgium if the Germans had not done so. We are concerned merely with the law. Of course, if Belgium had taken the slightest step toward uniting her forces with either of the belligerents as against the others, she would have forfeited her attitude of neutrality and become herself a belligerent, subject to be treated as an enemy. And this would be the end of her independent existence; for that is based upon the neutrality which the convenience of the great powers has determined upon as the condition precedent of her national life.

But, assuming that she committed no breach of neutrality,—what rights has Belgium or Switzerland or any other neutralized territory? It has the right to defend itself, as Belgium has done. She is not obliged to defend herself, but may choose whether she will do so or not. For, if she yield to superior force, that can not be looked upon as an un-neutral act; though it may place her during the war upon the side of one of the belligerents, as is the case of Belgium today in consequence of her defence. Still, Belgium had undoubtedly the right to defend her soil. The law is on her side in that regard.

But, on the other hand, what protection has she? Evidently nothing but the agreement under which she lives,—and that depends either upon the "interests" of the powers who made the agreement, as Sir Edward Grey said, or upon the convenience of respecting it, as the advance of the German army has proved.

In the heat of a savage conflict, the reasons for the agreement are destroyed and the agreement itself is torn to shreds; for there is no one to enforce it. The only force that exists is being exhausted in the war. The neutralized territory has rights that are not only recognized but also defined by international law. It has its guarantees as well,—equally recognized and defined, though, as in the present case, the authority of the law is gone, and how shall a method be found by which to guarantee the guarantees?

PHILADELPHIA,
April, 1915.

THE PRONOUNS AND VERBS OF SUMERIAN.

By J. DYNELEY PRINCE.

(Read April 23, 1915.)

The pronouns of a language are relics of its earliest demonstratives. The first desire of the primitive speaker must have been to indicate objects. So soon as nouns had evolved themselves in his mind, the next step was the development of an abbreviated form which could indicate substantives without repeating the noun itself, and these abbreviations or indicators were nothing more than pronouns. It is possible that there existed originally in primitive speech only a single impersonal element of this character, which was at first used, supplemented by gestures, to indicate objects of all three persons. Subsequently, the same syllable may have been tonally differentiated to indicate the 'I, thou, that' idea and still later, additional syllables were called into play to aid in differentiating the first, second and third persons. It is interesting to observe that in the very evidently extremely primitive system of Sumerian pronouns, all the personal particles contain the common demonstrative element *e*, which appears most prominently in the third personal *ene*.

The object of the present paper is to present in a concise form the results of grammatical investigations regarding the Sumerian pronominal particles and also to weigh these theories and conclusions from a philological point of view, especially in connection with the incorporation of the pronominal elements in the verbal structure. It is interesting to note that the distinction between the nearer and farther subject-object, herein noted in connection respectively with the *b* and *n* particles, is a most natural linguistic phenomenon which would have followed almost arbitrarily the evolution of the general demonstrative idea.

The material used in this treatise has been taken partly from the

new vocabularies published in Arno Poebel's "Grammatical Texts,"[1] with the main conclusions of which the present writer is forced to disagree, as the material offered by Delitzsch, Langdon and Prince seems to disprove Poebel's chief thesis of the hidden vowel of the first person.

I.

Separable Pronouns.

Mà-e, 'I,' according to Delitzsch, § 28 = *ma* + demonstrative *-e*. Langdon, p. 102, thinks that *mà-e* was pronounced *mö,* as he regards *a-e* as a diphthong, indicating an *Umlaut*. This is possible, especially as the writing *me-a* = *anaku,* 'I,' also occurs. The pronunciation was more likely *mǒ* than *mö*. The form *mà-e* was invariably used for the *status rectus;* note that in such cases as IV. R. 17, 40–41; *mà-e mu-un-ši-in-gí-en* = *ịaši išpuranni,* 'he has sent me,' the *mà-e* is really a *status rectus* in prolepsis and not an accusative, which would be regularly represented by the oblique *ma* (see just below). It is interesting to notice that Delitzsch gives *me-e* instead of *mà-e* as the usual form, which is again an indication that *mà-e* was not pronounced in two syllables, but really indicated an *Umlaut*. Delitzsch is, therefore, probably right in supposing that the writing *mà-e* really indicated original *ma,* the element of the first person, + the indicative *e*. All authorities are agreed that *a-e* may represent *e* or *ö* (cf. Delitzsch, § 18b).

The oblique form of *mà-e* is generally *ma,* as Poebel: gen. *ma-a-(k)*; cf. *ma-a-kam,* 'it is mine,' Poebel, p. 43; *ma-a-ge-eš ğe-ti* = *aššumia liblut̩,* 'for my sake may he live.' The Dative is regular: *ma-a-ra, ma-ra, ma-a-ar* (*passim*). In the locative, Poebel finds

[1] The following abbreviations have been used: AJSL: "American Journal of Semitic Languages"; ASKT. = Paul Haupt, "*Akkadische und Sumerische Keilschrifttexte*"; Br. = R. Brünnow, "Classified List of Cuneiform Ideograms," Leyden, 1887; Del. = Delitzsch: Friedrich Delitzsch, "*Sumerische Grammatik,*" Leipzig, 1914; EK. = *Eme-ku* dialect; ES. = *Eme-sal* dialect; HT. = ASKT.; JRAS. XVII. = "Journal of the Royal Asiatic Society," quoted Poebel, pp. 63 ff; Langdon = Stephen Henry Langdon, "Sumerian Grammar," Paris, 1911; MSL. = J. D. Prince, "Materials for a Sumerian Lexicon," Leipzig, 1908; P. = Poebel: Arno Poebel, "Grammatical Texts," Philadelphia, 1914; P. AO. 5403: quoted, Poebel, pp. 62–63; P. 142: quoted, Poebel, pp. 57 ff; PSBA. = "Proceedings of the Society of Biblical Archaeology"; Sfg. = Paul Haupt, "*Sumerische Familiengesetze.*"

ma-a, 'on me' (not in Delitzsch). The regular accusative is also *ma-a.*

Poebel (p. 42) gives *mu-me-en* as the full separate form of *ma-e,* which clearly contains the first personal element *m(u)* + *me-en* of the verb 'to be' = 'it is I who am' (cf. *s.v. me-ne,* 'we').

The regular suffix of the first person is *-mu,* not to be confused with the third personal *-mu* referred to below. It is now practically established that the first and second persons suffered a change of vowel in the oblique relation, and that the *-mu* in such cases became *-ma;* as *e-ma,* 'in my temple'; *uru-ma,* 'in my city'; *lugal-ma,* 'for my king,' etc. The difficulty in establishing any definite rule in this connection lies in the fact that both *mu* and *ma* appear indiscriminately for both *status rectus* and oblique (see both Langdon and Delitzsch for numerous examples). The probability is that the original usage of the earlier language was *mu* for *rectus* and *ma* for oblique, but, even in the early documents, we find the confusion of forms so evident, as to make it impossible to come to a definite conclusion. The former theory that *-ma* was the ES. form for EK. *mu* is undoubtedly incorrect. On *-ni* = 1 p. suffix, cf. below, *s.v. e-ne,* 'he, she, it.'

Za-e, 'thou,' according to Delitzsch, § 29 = *za* + demonstrative *e,* as in the case of *mà-e,* 'I.' Similarly Langdon, p. 102, thinks that *za-e* represented *zö,* but this, like *mà-e* = *mo̊,* was probably pronounced *zo̊.* (*o̊* = *a-e*). *Za-e,* like *mà-e,* was the invariable form of the *status rectus.* In such phrases as *kâtu amâtka* = *za-e e-nim -zu,* 'thy word,' *kâtu* is really the separable pronoun in nominative apposition. Cf. the remarks above on *mà-e* = *i̭aši.* Note that the second personal pronoun is also given as *ze,* in *ze-me,* 'thou art' (*passim*) and occasionally *zi-me,* Br., 3387.

The oblique of *za-e* is generally *za;* note Poebel: gen. *za-a(k),* *za-a-a(k)*; *za-a-ge;* dat. *za-ra, za-ar; za-a-šu* (KU), 'unto thee' and pure locative *za-a,* 'on thee' (Poebel), a case not in Delitzsch. The oblique *za* is always used with the postposition as *za-da,* 'with thee, from thee,' etc.

Poebel gives also the separable *ze-me-en,* corresponding to *mu-me-en,* 'I' (see, however, *s.v. za-e-me-en, s.v.* the second person plural).

The regular suffix of the second person is *-zu,* with usually oblique *-za,* as in the case of *-me, -ma* (see just above). But here also *-zu* is found as both *rectus* and oblique, although *-za* seems to have been the original oblique form. Cf. *mà-e eri-za,* 'I am thy servant' (*-za* for *-zu,* L., § 158); *ga-zu-ta,* 'at thy command' (probably should be *ga-za-ta,* etc.). It is not possible to predicate a regular usage for *-zu; -za.*

E-ne, 'he, she, it'; according to Delitzsch, § 30 = demonstrative *e* + demonstrative *ne* = *nê,* 'this.' This is clearly the same *ne,* seen in the plural of nouns and verbs. Langdon (p. 107) thinks that *e-ne* = a reduplicated *ni* with apocope of the first *n; i. e.,* a sort of plural form. This idea has little foundation, as the demonstrative *e*-element is well established in other forms (as, for ex., *mà-e, za-e, lugal-e,* the king, etc.) Poebel gives no separate form for *e-ne,* the probability being that *e-ne* itself served as such. There is no distinct oblique form of *e-ne* which is declined like a noun: gen. *e-ne-ge* (KIT); dat. *e-ne-ra, e-ne-ir;* loc. *e-ne-a,* 'upon him' (Poebel).

The suffix of the third person has a twofold aspect; viz., 1) -(*a*)-*ni* and *-ni,* the former being rarer in occurrence than the latter; the oblique of this form is *-na;* and 2) -(*a*)-*bi* and *-bi,* the former being rarer than the latter; the oblique form of this is *-ba* (Delitzsch, § 37). The same confusion of usage is seen here as that between *-mu, -ma* and *-zu, -za,* fully pointed out by Delitzsch, § 38; *ki-ba,* 'in its place'; *šu-na,* 'into his hand,' regularly oblique, but *a-na* = *abušu,* 'his father' (for *a-ni*) and *dam šà-ga-a-ni,* 'the man of his heart,' instead of *-a-na,* etc. As to the meaning of the *-n-* and *-b-* suffixes, Langdon (p. 105) believed that *-ni, -na* as both noun suffixes and verbal elements, originally denoted animate beings, while *-bi, -ba* indicated inanimates, but the logical continuance of this theory is not borne out by the facts. We may note that in one of Langdon's own examples *bi-e-nad-di-en,* 'he slumbers,' *bi-,* here as verbal prefix, represents an *animate* subject (cf. my review, AJSL. XXVIII. p. 73). Note also HT., p. 76, 1 and 9: *su-mu-ug-ga-ni* and *su-mu-ug-ga-bi,* 'his suffering,' in both cases animate. Delitzsch, § 40, also gives many examples. The suffix *-ni* is used for the first person in Br., 5334: *i-de tum-a-ni* = *ublim pâniya; ud tur-ra-ni-ta* = *ultu ûm cixriku,* 'from the days of my youth'; *lal-a-ni* = *candaku,* 'I am

yoked.' The only possible explanation is that the translator deliberately transferred the persons. The possibility that the *-n-* and *-b-* elements were originally used to denote the remote and nearer subject or object respectively, has already been pointed out by Thureau-Dangin, ZA. XX., pp. 380–404, and fully discussed by Poebel (ZA. XXI., pp. 218–230; Prince, AJSL., pp. 364–365). This theory, although not yet capable of entirely satisfactory demonstration, lends itself more readily to credence than the animate-inanimate idea. In the later language, which represents a period of grammatical decay, the *n* and *b*-suffixes appear to be used arbitrarily. It is probable, however, that in the earlier phases of Sumerian, these endings must have had the force of remote and nearer demonstratives respectively.

Me-ne, me-en-ne, 'we.' Poebel gives *me-en-de, me-de, me-en-de-en,* which, however, should be read *me-en-ne, me-ne, me-en-ne-en.* He uses the *d*-element, because he finds the oblique form *me-en-da-na,* 'without us' (p. 47) and also *nam-da-me-en-da-na,* 'without us'; viz., *nam* negative + prep. *-da* + first person plural *me-en* + prep. *da* repeated + *-na,* probably negative, repeated. Poebel's own form *me-da-nu* (p. 34, line 34), 'without us' clearly shows that the *me-en* in these *me-en-da*-forms is the *me-en* of the first person. Thus, *me-en-da-nu* = *men* first person + prep. *da* + negative *nu.* A form *me-en-de* eliminates the evident combination of *me* = first person + plural *-ne.* Similarly, Poebel's separate forms *me-de-en-de* and *me-de-en-de-en* must be read *me-ne-en-ne* and *me-ne-en-ne-en,* respectively; *me-en-ne* = 'we' + *en,* element of the verb to be; lit. 'it is we who are' (cf. *mu-me-en, s.v. mà-e* above).

According to Delitzsch, *-me-ne,* etc. = *ma* + *ene,* 'I and he,' a sort of exclusive 'we.' But if this were the case, we should expect to find also an inclusive 'we' = 'I and thou,' which would have the form *me-en-zi-en* (or *me-ze*), but this form actually occurs with the equation *attunu* 'you,' plural (just below). It is much more likely to suppose that *me-en-ne, me-en-ne-en* represent a pure plural of the first personal *mê(n)*; *i. e., mê(n)* + *ne* or *ne-ne* + the verbal *-en,* when the form ends in *-n.* The pluralizing of the first person singular occurs for example in Central American Tule *an-mala* = *an* 'I' + the collective *-mala.* Indeed, the form *men-men* is actually

a reduplication of the first personal singular = *me-* + verbal *-n.* We find the reduplicated suffix *-mu-mu* 'our' (see below), which confirms this view.

Me-en-ne declines regularly, although no genitive has been found as yet; probably = *me-en-ne-ge* (KIT); dat. *me-en-ne-ra, me-en-ne-ir;* loc. *me-en-ne-a,* these last two cases being given by Poebel.

The suffix of the first person plural appears as 1) *-mu-mu,* Langdon, p. 109, n. 1, although this is rare; 2) Clay, Miscellaneous Tablets, has found: *dumu-mu-meš* 'our child,' a direct plural of *-mu;* 3) as *-men* : *en-men* 'our lord,' Langdon, p. 103 (Delitzsch, § 33, gives *-men* as frequent in this sense); 4) the common suffix is *-me: ad-da-me* 'our father'; *ama-me* 'our mother'; *ki-me-ta* = *ittini* 'with us,' etc. The curious form *ki-me-ne-ne* = *ittišunu* 'with them,' Delitzsch, § 43, probably was wrongly translated and means 'with us'; *i. e., ki* 'with' + *me-ne-ne,* a pluralized form of the usual *-me.* There seems to be no distinction in these suffixes between *rectus* and oblique. This is clearly indicated by the series of suffixes *an-ne-en, en-ne-en, in-ne-en, me-en-ne-en, un-ne-en,* all which are used for the first person plural (MSL., p. xxii, § 5) and are not honorifics as I thought (AJSL., XXVIII., p. 73). These are merely plural first personal suffixes with possible connecters (cf. just below *s.v. me-en-zi-en*). The *-nen* element which appears in all of them must represent *-me-n.*

Me-en-zi-en = *attûnu* 'you' (given by all sources) and also *zi-ne* 'you,' a real plural of the second personal element *zi* (*ze* = *za-e*), Langdon, p. 104. Note the parallel *me-ne* 'we.' In view of the fact than *za-e-me-en* also = *attûnu,* IV. R. 21, 1 B. rev. 3, clearly = *za-e* + *men* = 'thou and I,' it is probable that *me-en-zi-en* also = 'I and thou' (*me,* 'I' + verbal *-en* + *zi*(*ze*), 'thou + verbal *-en*). But this *za-e-me-en* is equivalent to Poebel's full form of *za-e* (see above *s.v. za-e*). It is impossible that *za-e-me-en* could have been a second personal singular separate form and at the same time a second person plural! If it were really used in both senses there must have been a different tone for each usage of *men* = respectively the verb 'to be' and the first person. Note that the odd reading NI-*e-me-en,* HT. 139, § 7, clearly = *za*(*l*)*-e-me-en.*

Of *me-en-zi-en* no genitive has been discovered, but it probably

was *me-ne-zi-en-ge* (KIT); dat. *me-en-zi-en-ra* and *za-ra-an-zi-en* (!); loc. *za-a-an-zi-en*. In these two latter forms, we have a reduplication of the second person; *i. e., za* + dat. *-ra* + verbal $(a)n$ + the second personal *zi* with verbal *en* = *zaranzen* and *ża-a* loc. + $(a)n$ = second person + *zi* with verbal *en* = *zânzen*.

The suffix of the second plural is *-zu-ne*, as *mu-lu-zu-ne*, 'your lord,' Langdon, p. 104. Note that in Delitzsch, "*Sumerisch-Akkadisch-Hettitische Vokabularfragmente*," p. 19, the form *á-zu-šú-ne-a-áš* = *ana ittikunu*, 'for your wage' = the suffix *-zu-ne*, with infixed preposition *šú* (KU) + directive *a-áš*, an unusual and interesting example of infixation. The suffix *zu-ne-ne* often occurs, Delitzsch, § 42: *u-gu-zu-ne-ne* = *elikunu*, 'upon you'; *nam-en-un-un-zu-ne-ne* = *macartikunu*, etc. Here we have plainly the pure plural of the second personal element and no indication of 'thou and I.'

As in the case of the first person plural, there seems to be no distinction between *rectus* and oblique. This is indicated by the series of suffixes similar to those just cited in connection with the first person plural; *-ab-ci-en, -an-ci-en, -en-ci-en, -ib-ci-en, -íb-ci-en, in-ci-en, -me-ci-en, -me-en-ci-en* and *-un-ci-en*. The forms *-me-ci-en* and *-me-en-ci-en* may contain an 'I and thou' element. These all represent the second personal suffix with possible connecters.

E-ne-ne-ne, 'they'; according to Delitzsch, § 32; *ene* + *enene*, 'he and they,' but this form is more likely to be *ene*, 'he, she, it' + the reduplicated plural element *-ne*, as in the case of *me-ne* and *-zu-ne-ne*, cited above. The short form *e-ne-ne* is also common. Poebel gives *e-ne-ne-ne* as the full separate form, but without sufficient foundation, as either *e-ne-ne* or *e-ne-ne-ne* might have served in this capacity, as in the case of the singular *e-ne*.

The third person declines regularly; gen. *e-ne-ne-ge* (KIT); dat. *e-ne-ne-ra, e-ne-ne-ir;* loc. *e-ne-ne-a*.

The third plural suffix, as in the case of the third person singular, is twofold; 1) (*a*)*-ne-ne*, the *a* not being always present, in fact it is usually part of the prolonged root, as *dug-ga-nene*. It appears regularly *šu-ne-ne*, 'their hand'; *gir-ne-ne*, 'their foot; *ki-ne-ne-ta* = *ittišunu*, 'with them' (on *ki-me-ne-ne* = *ittišunu*, Delitzsch, § 43, see above *s.v. me-en-ne*). 2) The endings with the *b*-element: *bi-e-ne-ne, bi-e-ne*, Delitzsch, § 43; *be-ne-ne*, Langdon, p. 108, and

be-ne, Langdon, p. 108, are also common: *sib-bi-ne,* 'their shepherd'; *muğ-bi-ne-ne* = *elišunu* (Langdon, p. 108). The distinction between remote and nearer subject and object, respectively *-ne-ne* and *-bi-ne,* is no more logically carried out in the later language than in the case of *-ni, -bi* of the third person singular (*q.v.*), but their original remote and nearer force seems just as probable.

The third person plural possessive is frequently expressed by the singular suffixes of the third person: *-ni, -bi,* a phenomenon which

TABLE OF PRONOUNS.

	I	*Thou*	*He, She, It*
Nom.	*ma-e* Separate: *mu-me-en*	*za-e* Separate: *za-e-me-en*	*e-ne*
Gen.	*ma-a-(k)* *ma-a-ge*	*za-a(k)* *za-a-a(k)* *za-a-ge*	*e-ne-ge*
Dat.	*ma-a-ar* *ma-ra* *ma-a-ra*	*za-ra* *za-ar*	*e-ne-ra*
Loc.	*ma-a*	*za-a* (*za-a-šù,* 'to thee')	*e-ne-a*
	SUFFIXES	SUFFIXES	SUFFIXES
Rectus[2]	*-mu*	*-zu*[2]	(*a*)*-ni, -ni*[4] (*a*)*-na, -na*
Oblique	*-ma* (*-ni* very rare and probably an error)	*-za*	(*a*)*-bi, -bi*[4] (*a*)*-ba, -ba* *-mu*[5]

	We	*You*	*They*
Nom.	*me-ne, me-en-ne, me-en-ne-en*	*me-en-zi-en*	*e-ne-ne* *e-ne-ne-ne*
Gen.	[x]*me-en-ne-ge*	[x]*me-en-zi-en-ge*	*e-ne-ne-ge*
Dat.	*me-en-ne-ra* *me-en-ne-ir*	*me-en-zi-en-ra* *za-ra-an-zi-en*	*e-ne-ne-ra* *e-ne-ne-ir*
Loc.	*me-en-ne-a*	*za-a-an-zi-en*	*e-ne-ne-a*
	SUFFIXES[3]	SUFFIXES[3]	SUFFIXES[3]
	-me-en *-me* *-mu-mu* } rare *-mu-meš* } rare	*-zu-ne* *-zu-ne-ne*	*-*(*a*)*-ne-ne, -ne-ne* *-be-e-ne-ne*[3] *-be-ne-ne,* etc.

CONNECTING SUFFIXES
an-ne-en, en-ne-en,
in-ne-en, me-en-ne-en,
un-ne-en

CONNECTING SUFFIXES
ab-ci-en, an-ci-en,
en-ci-en, ib-ci-en,
ib-ci-en, in-ci-en,
me-ci-en, me-en-ci-en,
un-ci-en

[2] Confused usage.
[3] No distinction between *rectus* and oblique.
[4] Probable distinction between nearer and farther subject and object.
[5] Used only with participles, so far as is known. See below.

is seen in other languages, as, for example, in Central American Tule, where *a'ti, i'ti* can indicate both 'he, she, it' and also 'they' (Prince, Amer. Anthropologist, XV., p. 484; the *a'ti, i'ti* -element may be pluralized by the collective suffix *-mala,* which, however, is often omitted).

II.

Sumerian Verb with Pronouns, with References to Following Commentary.

I-Thee

Ga-class: *ga-mu-ra-ab-dím* = *lu-bu-ša-ku-um,* 'I will (let me) make for thee,' P., No. 142, rev. 2, 10.

Mu-class: *nu-mu-ra-te-mà-dè(ne)-en* = *u-la e-ṭe-xi-a-kum,* 'I shall not go to thee,' P. AO. 5403, 6. *xu-mu-ra-ab-gă(r),* 'I gave thee as a present,' P., p. 103.

Mi-class: *mi-ni-max-en,* 'I made thee great therein (for it),' P., p. 112.

I-Him

Ga-class: *ga-an-na-dím* = *lu-bu-su-um,* 'I will make it for him,' P., No. 142, rev. 2, 15.

Mu-class: *xu-mu-na-du,* 'I built for him,' P., p. 102. *mu-na-du,* 'I built for him,' P., p. 102. *xu-mu-ni-max* = *lu-ša-ti-ir,* 'I will increase for him' (or) 'therein,' P., p. 102.

Mi-class: *mi-ni-í* = *a-na-ku šu-a-ti šu-a-ti,* 'I it for him,' P. JRAS., XVII., 65, 4, 23. *mi-ni-du* = *al-bi-in,* 'I moulded it for him' (or) 'therein,' P., p. 102. *xu-mi-ni-in-tax* = *lu-um-mi-su,* 'I supported it,' P., p. 102.

Ne-class: *ne-gí-a,* 'I restored it (Clay).'

Ba-class: *ba-a* = *a-na-ku šu-a-ti(+ -ti;* probably = *šuati šuati),* P. JRAS., XVII., p. 65, 4, 19. *ba-ni-í* = *a-na-ku šua-ti šu-a-ti,* 'I it for him,' P. JRAS., XVII., p. 65, 4, 28 (also *ba-ni-e* ditto). *ba-an-na-te-en e-te-xi-šum,* 'I went to him,' P. AO., 5403, 8.

Bi-class: *bí* = *a-na-ku šu-a-ti,* 'I it (or) him,' P. JRAS., XVII., p. 65, 4, 13. *bi-i* = *a-na-ku šu-a-ti,* 'I it (or) him,' P. JRAS., XVII., p. 65, 4, 14.

I(n)-class: *i-ni-í* = *a-na-ku šu-a-ti šu-a-ti,* 'I it for him,' P. JRAS., XVII., p. 65, 4, 22. *in-na-ni-í* = *a-na-ku šu-a-ti šua-ti u*

a-na-ku šu-a-šum, 'I it for him and I to him it,' P. JRAS., XVII., p. 65, 4, 30.

I-Him

sag-túm-ma i-ni-in-ga = ma-gi-ir-tam ak-bi-šum, 'I spoke favorably to him,' P. No. 142, rev. 3, 21. *in-na-te-en = e-iṭ-xi-šum,* 'I have gone to him,' P. AO. 5403, 2.

Im-class: *ù-gul im-ma-an-mà-mà,* 'I asked him,' P. p. 102.

Thou-Me

Ma-class: *nam-ma-te-má-dé (ne)-en = la ta-ṭe-xi-a-am,* 'do not come to me,' P. AO. 5403, 5.

Mu-class: *nam-mu-un-xa-xa-en = la tu-te-bi-da-(an-ni),* 'mayst thou not be lost to me,' P. No. 142, rev. 3, 8.

Thou-Him

Postpositive class: *dím-(ma)-na-ab = e-bu-su-um,* 'make for him,' P. No. 142, rev. 2, 14. *gur-an-ši-ib,* 'turn to him,' P. No. 142, rev. 2, 16. *te-a-na = ṭe-xi-šum,* 'go to him,' P. AO. 5403, 1. *na-an-na-te-mà-dè (ne)-en = (la) te-ṭe-(xi)-šu-um,* 'do not go to him,' P. AO. 5403, 4.

Mi-class: *mi-ni-e = at-ta šu-a-ti- šu-a-ti,* 'thou it it,' P. JRAS. XVII. p. 65, 4, 25.

Ba-class: *ba-e = at-ta-ku* (*sic* !) *šu-a-ti,* 'thou it,' P. JRAS. XVII. p. 65, 4, 20.

Bi-class: *bi*-ne = *at-ta šu-a-ti,* 'thou it,' P. JRAS. XVII. p. 65, 15. *bi-e = at-ta šu-a-ti,* 'thou it,' P. JRAS. XVII. p. 65, 16.

I(n)-class: *i-ni-e = at-ta šu-a-ti šu-a-ti,* 'thou it it' or 'it for him,' P. JRAS. XVII. p. 65, 4, 24. *in-na-ni-e = at-ta šua-ti šu-a-ti,* 'thou it for him,' P. JRAS. XVII. p. 65, 4, 32. *in-na-te-e-en = te-iṭ-xi-šum,* 'thou hast gone to him,' P. AO. 5403, 9, also 'go to him,' ditto, 2. *in-da-má-e-en = ta-ša-(ka)-aš-(šu)-mu,* 'thou shalt place it upon him,' P. AO. 5403, 10.

He-Me

Ma-class: *ma-an-si = i-din-nam,* 'he gave it to me,' P. p. 110. *igi . . . ma-ni-in-du-a,* 'when he looked upon me,' P. p. 104. *igi . . . mu-ši-in-bar-ra,* 'when he looked upon me,' P. p. 102. *ma-a-ar ma-an-du-ga,* 'when he commanded me,' P. p. 104. *ma-ra ma-an-du-ga,* 'when (to build) she ordered me,' P. p. 105. *xa-ma-ab-*

dím-e = *li-bu-ša-am,* 'may he make for me,' P. No. 142, rev. 2, 22.

MU-CLASS: *mu-ub-dim-e* = *i-bu(pi)-ša-am,* 'he made for me'; P. p. 57, rev. 3, 19, renders 'makes'(?). *nu-mu-ub-dím-e* = *u-la i-bu-ša-am,* 'he did not make for me,' P. No. 142, rev. 3, 20. *sag--túm-ma mu-un-ga* = *ma-gi-ir-tam ik-bi-a-am,* 'he spoke favorably to me,' P. No. 142, rev. 3, 21. *sag-ki . . . mu-ši-in-bar,* 'he looked on me,' P. p. 105. *mu-na-an-si,* 'he has given to me,' P. p. 110. *nam mu-un-tar,* 'he determined fate for me,' P. p. 105.

MI-CLASS: *nam-mu mi-ni-in-tar-ra,* 'after he had determined fate for me,' P. p. 105.

HE-HIM

MU-CLASS: *mu-na-ni-in-gi-gi,* 'he replied to me,' P. p. 93. *u . . . mu-na-an-si-ma-ta,* 'after he had given to him,' P. p. 105. *mu-na-ni-in-du,* 'he had built for him therein,' P. p. 105. *mu-na-an-ši-in-gar,* 'he made it for him,' P. p. 106.

MI-CLASS: *mi-ni-in* = *šu-u šu-a-ti šu-a-ti,* 'it for him,' P. JRAS. XVII. 65, 4, 27. *mi-ni-in-tar-ra,* 'when he had determined it for him (it),' P. p. 112.

BA-CLASS: *ba-on* = *šu-u šu-a-ti,* 'he it,' P. JRAS. XVII. p. 65, 4, 21. *ba-an-na-te* = *i-ṭe-xi-šum,* 'he went to him,' P. AO. 5403, 7.

BI-CLASS: *bi-in* = *šu-u šu-a-ti,* 'he it,' P. JRAS. XVII. p. 65, 4, 17–18. *šu-ni bi-in-si-a,* 'after he had placed it in his hand,' P. p. 105.

IB-CLASS: *ib-ri-tuk,* 'he shall receive for it,' (Clay).

I(N)-CLASS: *i-ni-in* = *šu-u šu-a-ti,* 'he it it,' P. JRAS. XVII. p. 65, 4, 26. *in-na-ab-si-mu* = *in-na-din-šu,* 'he shall give it to him,' P. p. 94. *in-na-ab-gi-gi* = *ip-pa-alšu,* 'he shall answer it to him,' P. p. 94. *in-na-ab-gur-ri* = *u-ta-ar-šu,* 'he shall return it to him,' P. p. 94.

THEY-ME

MU-CLASS: *xu-mu-ši-in-bar-ri-eš* = *lu-ip-pa-al-su-um,* 'they have looked upon me,' P. p. 104. *sag-e-eš xu-mu-*PA-TUG-DU-*eš,* 'they have given it to me as a gift,' P. p. 104.

BI-CLASS: *šu-mu-šù bi-in-si-eš-a,* 'when they gave it into my hands,' P. p. 104.

THEY-THEE

PRECATIVE CLASS: KA *xa-ra-ab-ša-ša-gi-ne* = *li-iš-te-mi-ga-kum*, 'may show reverence unto thee,' P. p. 110.

THEY-HIM

PRECATIVE CLASS: *xe-e-en-na-ab-dím-e-ne* = *li-bu-šu-šum*, 'may they make for him,' P. No. 142, rev. 2, 17.

MU-CLASS: *mu-un-ni-in*-PA-TUG-DU-*a*, 'when they had given to her as a gift,' P. p. 112. *mu-na-an-si-mu-uš-a* = *i-ti-nu-šum*, 'when they had given it or gave it to him,' P. p. 104. *mu-na-an-gi-ni-eš-a* = *u-ki-in-nu-šum*, 'when they had made secure for him,' P. p. 104.

I(N)-CLASS: *in-na-ab-ka-la-gí-ne* = *u-dan-ni-nu-šum*, 'they shall pay him,' P. p. 104. *na-an-na-ab-dím-e-ne* = *la i-pi-šu-šum*, 'may they not make for him,' P. No. 142, rev. 2, 18.

COMMENTARY.

1. *Ba-*, 'I' (*s.v.* I-HIM); cf. also IV. R. 14, obv. 20 a: *ki-bi-gar-ra ba-ni-ib-dur-ru* = *ina tâkulti lûšešib*, 'I will invite (them) to a feast'; probably first person, but the text is broken.

2. *Ba-*, 'thou' (*s.v.* THOU-HIM); not an uncommon usage. Cf. AJSL. XIX., §20; IV. R. 17, 45 a; in IV. R. 30 nr. 3, rev. 15, there occurs a series of *ba*——*ne* forms all = 2 p. It is possible that the Assyrian scribe changed them from a 3 p. which perhaps was used for a general "you" like German *man*; French *on*.

3. *Ba-*, 'third person' (*s.v.* HE-HIM); occurs *passim*.

4. *Bi-*, 'I' (*s.v.* I-HIM); an unusual prefix in this sense.

5. *Bi-*, 'thou' (*s.v.* THOU-HIM); an unusual prefix in this sense. *Bi-*, as a *prefix*, is unusual in any case, even as the third person, as it is a common third personal *suffix*.

6. *Bi-*, . . . *-eš*, 'they' (*s.v.* THEY-ME); not common, although, if *bi-* is used in the singular 3 p., it is natural to find *bi-*, . . . *eš* for the plural.

7. *Ga-*, 'I' (*s.v.* I-THEE; I-HIM); a very common first personal prefix, probably from the cohortative *ga*; in fact, *ga-* was really cohortative originally, although it is frequently used in the sense "I will." Cf. Del., § 157, and AJSL. XIX., §23. It also = 1 p. in HT. 119, obv. 22: *ga-nu ga-ni-lax-en* = *alkam î nilliksu*, 'come let us go.' Note that is 1 p. plural here. On the other hand, *ga-* is used for the 2 p., IV. R. 11, 45 b: *en-nun ga-ne-tuš* (KU) = *ana maccarti tûšêšib*, 'thou shalt sit in the watch'; cf. AL.[3] 134, obv. 1: *an-sud ud-ag bil-gim sar-ki-ta za-e ši-in-ga-me-en bil* = *nûr šamê ša kîma išatim ina mâtim napxat attîma*, 'the light of the heaven which like fire in the land shines art thou, fire.' *Ga-* also may be used for the 3 p.; IV. R. 11, 19–20 b: *mu-uš-ku-pi azag-ga-na-ta a-an ga-mu-ri-a-bi* = *ina uznišu ellîti minam ixsusa*, 'what has he planned with his brilliant ears.'

8. *Im-*, 'I' (*s.v.* I-HIM); cf. also IV. R. 6, 41 b: *ki-ta im-mi-in-ri*, 'I

placed it at the bottom,' but used with a preceding *mà-e*, 'I.' *Im-*, however, can mean "thou"; II. R. 16, 16 e: *er* (A-SI) *im-ma-an-šeš-šeš* = *tabakki*, 'thou weepest.' *Im-* is very common as a third personal prefix.

9. *In-*, 'I' (*s.v.* I-HIM). Very rare. Poebel's examples are the best instances of this use.

10. *In-*, 'thou' (*s.v.* THOU-HIM); IV. R. 7, 30 a: *nin ma-e nin-zu-a-mu za-e in-ma-e-zu* = *ša anâku idû atta tîdi*, 'what I know thou shalt know' (= 'for me' = *-ma-e-*?); cf. AJSL. XIX., § 28. *In-* is commonly used with the third person.

11. *In-*, . . . *-ne*, 'they' (*sv.* THEY-HIM); a logical third person plural.

12. *Ma-*, 'me, to me' (*s.v.* HE-ME); for this usage Poebel's examples are best. Note also *ma-an-se* = *iddinšu*, 'he gave it to him' with the third person, Br. 4418.

13. *Mi-*, 'I' (*s.v.* I-THEE). Poebel's example is the only one known to me.

14. *Mi-*, 'me' (*s.v.* HE-ME; HE-HIM). Note that the *-nin-* here = '*me.*' *Mi* is most common with the third personal sense, Br., p. 546.

15. *Mi-*, 'thou' (*s.v.* THOU-HIM); cf. also IV. R. 24, nr. 3, 6–7: *tul-tul-aš mi-ni-in-šid* = *tilâniš tamnu*, 'thou regardest it as a ruin,' but points back to a 2 p. *-zu* in line 3.

16. *Mu-*, 'I' (*s.v.* I-THEE; I-HIM); very common use (see AJSL. XIX., § 32).

17. *Mu-*, 'thou' (*s.v.* THOU-ME); only in Poebel, so far as I have met it.

18. *Mu-*, 'he' (*s.v.* HE-ME; HE-HIM); *passim;* AJSL. XIX., pp. 217–218.

19. *Mu-* . . . *-eš*, 'they' (*s.v.* THEY-ME); a natural plural of *mu-*, 'he.' Note *mu-* . . . *-uš*, the same plural, as *mu-* . . . *eš* with vowel harmony; *uš* for *eš*.

III.

Analysis of Material.

The prefixes, infixes and suffixes shown by the above table may be grouped alphabetically as follows:

an-ši-ib, '(turn thou) it to him' = *šib*.

ba- = 1, 2 and 3 p. subject.

ba-an-, 'he it.'

ba-an-na-, 'he it; he for him.'

bi- = 1, 2 and 3 p. subject.

bi- . . . *-eš* = 3 pl. subject.

ga- = 1 p. subject.

ga-mu- = 1 p. subject: 'I will.'

ǧen- . . . *-e-ne* = 3 p. pl. precative subject.

i- = 1 p. subject; cf. *i-ni-in*.

i(b)- = 3 p. subject.

im- = 1, 2 and 3 p. subject.

i-ni-in-, 'I to him.'
in- = 1, 2 and 3 p. subject.
in-na-, 'I to (for) him.'
in-na-ab-, 'he (they) to him.'
ma- = 2 p. subject; 3 p. subject: 'he to me.'
ma-ab-, 'he it for me.'
ma-an-, 'she (he) . . . me' (acc.).
ma-ni-in-, 'he upon me.'
mi- = 1, 2 and 3 p. subject.
mi-ni, 'I thee therein; I it for him; he it for me.'
mu- = 1, 2 and 3 p. subject. Note also the following:
mu- . . . *-eš* = 3 p. subject.
mu-na-an-, 'he to (for) him; he it to me; they it for (to) him.'
mu-na-ni-in-, 'he it for me.'
mu-ni-, 'I for him.'
mu-ši-in-, 'he for me.'
mu-un-, 'he for (to) me.'
mu-un-ni-in-, 'they it for (to) her (him).'
-na-, 'for (to) him.'
-na-ab-, 'it for (to) him.'
-ni-i-, 'for him'; *mi-ni-i-*, 'I for him; thou for him'; *ba-ni-e-*, 'I it for him'; *i-ni-i*, 'I it for him.'
-ra-, 'to thee.'
-ra-ab-, 'it for thee.'

Analyzing the above elements stlil further, we observe that the first personal subject may be denoted by: *ba-; ga-; ga-mu-; im; in-; i-; mi-; mu-*.

The second personal subject may be denoted by: *ba-; bi-; in-; ma-; mi-; mu-; mu--eš* (pl.).

The third personal subject may be denoted by: *ba-; bi-eš* (3 pl.); *i(b)-; in-; ma-; mi-; mu-*.

In other words *ba-, im-, in-, mi-,* and *mu-,* may indicate the 1, 2 and 3 persons indiscriminately, and that *ma-* = 2 and 3 persons, while *ga-* is almost always used for the 1 p.

Nor is the problem made easier by the tabulation of the 1, 2 and 3 personal objective infixes; viz., 1 p. object: *ma-*, 'he to me'; *ma-ab-*, 'he it for me'; *ma-an-*, 'she (he) . . . me' (acc.); *ma-ni-in-*,

'he upon me'; *mi-ni-*, 'he it for me'; *mu-na-an-*, 'he it for me'; *mu-ši-in-*, 'he upon me'; *mu-ub-*, 'he for me'; *mu-un-*, 'he for (to) me.'

The second personal object shows: *mi-ni-*, 'I thee therein,' but consistently *-ra-*, 'to thee; thee'; *-ra-ab-*, 'it for thee.'

The third personal object is seen in *ba-an-*, 'he it'; *ba-an-na*, 'he it; he it for him'; *in-na*, 'I to him'; *mu-na-an-*, 'he to (for) him; they it for him'; *mu-un-ni-in-*, 'they it for her (him).' The element *-na* clearly = 'to him,' as *na-ab* = 'it for him'; *-ni-i-*, 'for him,' as *ba-ni-i*, 'I it for him'; *i-ni-i*, 'I it for him'; *mi-ni-i-*, 'I for him; thou for him.'

We find in these forms the duplicate *mi-ni-i-*, 'I thee therein' and 'I for him' = 1 and 3 object; *mu-un-*, 'he for me,' but *mu-na-an-*, 'he it for me' and 'he it for him.'

Poebel's table of pronominal elements as used by the verb (p. 45) is most ingenious, but not satisfactory, as will be shown. His classification is as follows:

	Infixed.	Enclitic.	Absolute.	Suffix.
1 p.	'	*m*	*m* (*de* and *en*)	*en*
2 p.	*e*	*z*	*z* (and *en*)	*en*
3 p.	*n*	*n*	*e*	*e*
Collective	*b*	*b*		

This he has elaborated from his Paradigms (pp. 70 ff); thus: *ni-la-en*, 'I pay'; *n* is preformative + the *i* which contains the 1 p. '; *la* = *root* + *en*-suffix of the 1 and 2 p.; *ni-la-en* also = 'thou payest'; only here, he thinks, that his 2 personal *e* is contained in the *i* of *n-i*. *Ni-la-e* also means 'he pays,' where the *n* = preformative of the third person + connecting vowel *i* + root *la* + 3 personal suffix *-e*. The analysis of the forms, just given is my own, made from what I believe to be his theory. The '-vowel for the first person again appears in the simple forms *i-dim*, 'I made'; the *e*-vowel of the second person in *e-dim*, 'thou madest' and the *n* of the 3 p. in *indim*, 'he made' (p. 78). Similarly *a-tum*, 'I brought' (*a* = *a*'); *a-mên*, 'I am' (Clay); *e-tum*, 'thou didst bring' and *an-tum*, 'he brought' (p. 80) seem to indicate the correctness of his idea. But, without entering more deeply into this ingenious and carefully thought out theory, it may be demolished by the simple fact that *a-* (= *a*'), *e-* and *n-* do not always mean the 1, 2 and 3

persons, although *a-* and *e-* *usually* occur in this sense. Thus, *a-* indicates the 3 p.: *a-rim-rim-ne*=*iṭ-ṭi-bu-(u)*, 'they have been immersed'; *kas-? a-ab-du*(KAK)=*ši-ka-ra i-ba-ba-di* and *a-ne-in-gi-*=*ik-?-šu*, both clearly third persons, although the meaning of the stems is unknown (cf. Br., p. 548). On the other hand, *a-* generally indicates the 1 p. (Prince, AJSL. XIX., p. 211). The prefix *e-* is frequently used of the 3 p. as: *e-ag*, 'he made'; *e-gaz*, 'he killed'; *e-gen*, 'he went' (Delitzsch, § 135 and § 184a). As for *n(i)*, Poebel himself gives examples cited above of *n(i)* used for both the 1 and 2 persons, while for the 3 personal use, cf. Br., p. 543: *ni-zu*=both *i-du-u*, 'they know' and *ti-di*, 'thou knowest'; *ni-gal* (IK)=*i-ba-aš-ši*, 'it is,' etc. *ad nauseam*. In other words, *a*, *e* and *n(i)* appear used for all three persons indiscriminately with a preference in favor of the 1, 2 and 3 persons respectively. On the other hand, is Poebel correct in supposing that the suffixed forms *-en* attached to verbs are characteristic of the 1 and 2 persons only? As in the case of *a*, *e* and *n* they appear indiscriminately for all three persons: *ni-la-en*, 'I pay'; 'thou payest,' as cited above, but *mu-un-tag-en*=*in-naq-qu-u*, IV. R. 19, 48 b; *mu-un-ši-in-gí-en*=*iš-pu-ra-an-ni*, 'they have sent me,' Br., p. 560. As to Poebel's 3 p. *-e*, it, of course, occurs often with the 3 p.; cf. *til*(BE)*-e*=*ig-da-mar*, Br., 1499, etc., but also *an-na-ab-uš-e*=*tu-ša-ax-xa-za-šu*, 'thou shalt cause him to seize it'; it is also a frequent sign of the imperative, as *kú-e*=*akul*, 'eat thou'; *uš-e*=*ri-da-an-ni*, 'have connection with me,' Br., 553.

There can be no doubt that Poebel is right in giving *m-z* and *n-b* as the respective characteristics of the endings of the postpositive conjugation, as *-mu-*, *-zu-* and *-ni*, *-na-* and *-bi-*, *-ba-* are the ordinary 1, 2 and 3 personal suffixes, respectively, of the postpositive *ḫâl*-clause; yet even here we find a variation, as the third person also appears with the ordinarily first personal *-mu* in relative clauses. This is the so-called *-mu* of the third person which I believe I was the first to call attention to (MSL. XXIX, § 32). The best illustration of it will be seen in the following phrases from IV. R. 27, No. 1, 4–11:

šinig-ga šar-šar a nu-nag-a-mu
bi-i-nu ša ina mu-sa-ri-e me-e la iš-tu-u

the grain which hath drunk no water in its bed;
sugur edin-na pa nu-sìg-ga-mu
kim-mat-su ina ci-e-ri ar-ta la ib-nu-u
whose bud in the field no shoot has borne;
GIŠ-A-AM *šita* (RAT)*-na ba-nu-su*(*g*)*-ga-mu*
il-daq-qu ša ina ra-ṭi-šu la i-ri-šu
the sprout which in its water-ditch is not planted;
GIŠ-A-AM *ur-ra ba-ab-bu-ra-mu*
(*il-daq-qu*) *ša iš-da-nu-uš in-na-as-xu*
the sprout whose roots have been torn away;
gu šar-šar-ra a nu-nag-a-mu
qu-u ša ina mu-sa-ri-e me-e la iš-tu-u
the vegetation which in its bed has drunk no water;

A similar construction to the above is undoubtedly that in ASKT., p. 122, 16: *eri-zu-ka ág-gig-gá ak-a-mu* = *ana ar-di-ki ša ma-ru-uš-tum ep-šu*, 'unto thy servant (fem.) who has (lit. 'makes' = *ak*) sickness.'

It is perfectly evident from the above examples that we have here a purely relative *-mu* used with participles. This is probably identical in derivation with the demonstrative *mu-* in the regular relative pronoun *mu-lu* and also with the common *mu*-prefix of verbs. It is quite possible that this relative *-mu* was used to indicate all three persons, like the *mu*-prefix in verbs.

What then are we to conclude as to the pronominal use with the Sumerian verb? Is it possible to imagine a verbal system with no fixed method of expressing the pronouns? The existence of the practically fixed second personal value of the infix *-ra-* and of the very common use of *ga-* as a first person would lead us to suppose that the verbal prefixes were really not indeterminate pronominally, even though Delitzsch lays down the rule that there is no second personal conjugation in Sumerian (p. 102).

The existence of third personal elements has long been recognized. The difficulty lies in the apparently indiscriminate use of many verbal prefixes for all three persons and the fixation of this usage by Poebel's undoubtedly valuable equations. The question now is whether Poebel is right in supposing that there underlies in every case of a first personal usage the '-vowel, *i. e.*, that *mu-*, 'I'

stood for *mu-*', while *mu*, 'he' did not contain this element. This is equally true of the *e*-prefix of the second person varying with *i*, cited by Poebel as characteristic. Are we to understand an *e*-element hidden in every second personal equation; *ba-*, *im-*, *in-*, *mi-*, *ma-*, *mu-*? The latter question must be answered in the negative, because, as just shown, *e* was not used exclusively of the second person. An examination of the paradigms as given by me in this paper will show the improbability of such a proposition.

The first thought which strikes the philologist studying this maze of apparently contradictory forms suggests the theory that in Sumerian, as in other languages, person in the verb must have expressed by the tone. This idea I suggested in AJSL. XIX., pp. 205–206, but no Sumerologist has ever gone into the matter. All scholars in this line have preferred, either to deny the distinction of pronouns by the verbal prefixes or else to suggest a difference in quantity (Paul Haupt, Sfg., p. 19, n. 6; Bertin, PSBA. V (1882–3), pp. 19 ff). But a difference in quantity or "accent," as some call it, would have been indicated at least by a prolongation of the vowel of the prefix. Real voice-tone would not have been so designated, any more than it is Chinese Wen-Li to-day. Grammatical tones actually exist in African Yóruba, as *ile ṛe*, 'thy house' but *ile ṛê* (another tone), 'his house'; in this language *o* = 'thou' but *ô* (another tone) = 'he, she, it.' Nothing could be more suggestive than this parallel (cf. S. Crowther, "Grammar of the Yóruba Language" (London, 1852), p. 12). I cite it, not of course with the intention of connecting Sumerian with Yóruba, but simply to demonstrate the possibility of toned grammatical elements which do not occur in Chinese. The three persons expressed by *ba-*, *im-*, *in-*, *mi-* and *mu-*, the two persons by *ma-* and the similar apparently indiscriminate use of the infixes, noted above, all point only to such a solution, which is far more reasonable than the idea that hidden vowels exist in such prefixes and infixes. If these vowels were present, how were they distinguished? There is nothing in the inscriptions to betray their existence. The Chinese do not indicate tones in their writing, because they are as readily understood by the reader of a living language, as an English reader understands the distinction between words of identical sound and difference of mean-

ing such as 'so, sow' and 'sew'; 'low'='below' and the verb 'low,' etc. Similarly, the Babylonian priest to whom Sumerian was, if not in later times actually a living tongue, at least a pronounced idiom, would never have thought of indicating the tonal differentiation of the grammatical verbal elements. The very poverty of Sumerian phonetically and the apparent monotony of its consonantal elements go to show the necessity of supposing some special unindicated means of differentiation. There seems to be every reason to suppose that such elements cited above as *ba-*, *im-*, *in-*, *mi-*, *mu-* indicating the first, second and third persons in the verbal scheme must have been tonally differentiated.

There are only about eleven distinguishing consonantal elements in the language; viz., *b*, probably = near object and near demonstrative; *d* = partitive; locative; means; *g* = precative and intentional; hence, future (= also *ng* = *n*); *ǧ* = pure precative optative, indicated herein by *x*; *l* (rare) = *n*; *m* = demonstrative and relating; *n*, probably = remote object and demonstrative; *r* = ethical dative; motion, direction towards, and perhaps rhotacism for *z* in the second person *-ra*; *š* = direction towards, similar to *r*, with which it may be connected etymologically; *t* = 'in' or 'out of'; location in general; *z* = pure second person, the only fixed consonontal grammatical value. Combine with these elements the vowels *a* = direction and *i* (*e*) = completed action, past and future, having a force like the Slavonic "perfective" forms, not forgetting that *i* may be the harmonic equivalent of *e* and *u* of *a*, and we get a reasonable explanation of most of the prefixes and suffixes of the language, particularly of the verbal prefixes treated above. See for a full discussion of these points, Prince AJSL. XXIV. pp. 354–365, and also in Encyclopaedia Britannica, XXVI, p. 77.

Poebel's infixes (pp. 70 ff), all which are, of course, well known, I will amplify by the following examples for the sake of clearness: *na*, 'to him'; *in-na-an-ba-e* = *uqassu*, 'he gives to him' = *na*, 'to him' + *n*, 'it' remote; *in-ne-la-e*, 'he will pay to them' (*-ne*); cf. *mu-ne-gen*, 'he went to him'; note that *šin* = 'them,' HT., p. 46, 25; *in-ši-in-se*, 'he gave to them'; *ma-la-e*, 'he will pay me'; here the *m* stands for the 1 p. + the directive *a*; *mu-ra-la-e*, 'he will pay thee'; the *mu* contains the demonstrative *m* + the tonal vowel of the

third person + the 2 p. *-ra-; in-ši-la-e,* 'he will pay to him': *i,* the perfective vowel + *n* = remote object 'it' + *ši* directive; *mu-ši-la-e,* 'he will pay to me'; the tonal *mu* of the 1 p. + directive *ši; mu-e-ši-la-e,* 'he will pay for thee': demonstrative *m* + tonal *u* of the second person + perfective *e; i(n)-ni-la-e,* 'he will pay upon (= for) it' = perfective *i* + remote object *n* + perfective *i* again + *ni,* really = 'therein'; *i(n)-na-ni-la-e,* 'he will pay to him upon it'; same as the above with the directive *na*-insert; *ib-ta-la-e,* 'he will pay from it (out of it)'; perfective *i* + nearer object *b; i(n)-na (b)-ta-la-e,* 'he will pay to him from (out of) it'; same as above with directive *na* + nearer object *b; ib-da-la-e,* 'he will pay together with it'; better 'by means of it'; *ib* as above with the *da* of means; *mu-e-da-la-e,* 'he will pay together with thee' demonstrative *m* with tonal *u* of the second person + perfective *e* + *da* as above. Poebel's whole set of infix-paradigms may be explained satisfactorily following this system.

THE HALL AND CORBINO EFFECTS.

By E. P. ADAMS.

(*Read April 22, 1915.*)

About four years ago Professor Corbino[1] described some effects which are closely related to the Hall effect. These new effects all have to do with the production of a secondary circular current in a metallic disk when a primary radial current is sent through it, and the disk placed in a magnetic field perpendicular to its plane. The only metal in which Corbino was able to detect any of these effects was bismuth, perhaps owing to lack of sensitiveness in his methods, but more probably because he seems to have neglected to take the precaution of preventing circular currents in a parallel disk used to lead the radial current into the disk under investigation. These circular currents would produce an effect which would largely balance the effect sought.

Last year Mr. Chapman and I[2] measured this Corbino effect in twelve different metals. In two other metals, tin and zinc, the effect was too small to measure. The method of measurement consisted in measuring the current induced in a coil of wire placed parallel to the disk when the radial current was reversed about twenty times a second by a rotating commutator.

The result of these measurements showed that the circular current C, produced, was proportional to the magnetic field, H, and to the radial current, I, or

$$C = aHI.$$

In the magnetic metals and in bismuth a is not constant but it depends on the magnetic force. In all the other metals tried a appears to be constant.

In order to compare this effect with the Hall effect, we may

[1] *Physikalische Zeitschrift*, XII., pp. 561, 842, 1911.

[2] *Philosophical Magazine*, XXVIII., p. 692, 1914.

assume that the effect of the magnetic field is to produce an electric intensity at right angles to both the magnetic force and to the primary electric intensity, and proportional to their product and the sine of the angle between them. This we may take to be:

$$E' = cVHE,$$

where V stands for the vector product. Applying this to the Corbino effect in a circular disk where r_2 is the external radius and r_1 the internal radius we find:

$$E = \frac{I}{2\pi ktr},$$

where I is the whole radial current, k, the specific conductivity, and t the thickness. Then the transverse electric intensity is

$$E' = \frac{cIH}{2\pi ktr}$$

and the whole circular current:

$$C = \frac{c}{2\pi} \log \frac{r_2}{r_1} \cdot IH.$$

Therefore the constant a is equal to $(c/2\pi) \log (r_2/r_1)$

$$c = \frac{C}{IH} \frac{2\pi}{\log \frac{r_2}{r_1}}.$$

We may now make the same hypothesis about the Hall effect. Here it is known that if a current I flows through a rectangular sheet metal of length l, breadth b, and thickness t, there is a transverse difference of potential given by

$$e = R\frac{HI}{t},$$

R being the Hall constant. The transverse electric intensity is now

$$E' = \frac{cHI}{kbt},$$

and thus the transverse difference of potential is

$$e = \frac{c}{k}\frac{HI}{t}.$$

Thus

$$R = \frac{c}{k}.$$

The constant c may be determined from both the Hall and Corbino effects. Experiments that Mr. Chapman has recently been making show that c is the same when measured by the two effects.

Now it is known that the Hall effect varies in sign from metal to metal. This change in sign may be introduced in the hypothesis by supposing that the constant c varies in sign for different metals. The experiments that have been made show that the Corbino effect changes in sign with the Hall effect. Thus there can be little doubt that these two effects are essentially the same, and that any explanation of one effect will explain the other.

Corbino also showed that when a disk carrying a radial current was placed in a magnetic field so that the normal to the disk made an acute angle with the direction of the field, a torque was brought into play tending to make the disk parallel to the field. If ϕ is the angle between the normal to the disk and the magnetic force, the mutual energy of the circular current and the magnetic field is

$$W = \frac{c}{8\pi} \cdot IH^2S \cos^2 \phi,$$

where S is the area of the disk. Thus the torque tending to increase ϕ is

$$-\frac{\partial W}{\partial \phi} = \frac{c}{8\pi} IH^2S \sin 2\phi.$$

Mr. Smith has succeeded in measuring this torque in four or five different metals, including bismuth, and the values of c calculated from his results are in good agreement with those obtained from the measurement of the circular current.

The production of a circular current in a disk by a magnetic field acting on a radial current implies an increase in its resistance.

This increase may be readily calculated. The rate of heat production by the radial current is

$$\frac{I^2 \log \frac{r_2}{r_1}}{2\pi kt}.$$

By the circular current it is

$$\frac{2\pi C^2}{kt \log \frac{r_2}{r_1}} = \frac{c^2 I^2 H^2 \log \frac{r_2}{r_1}}{2\pi kt};$$

the total rate of heat production is thus

$$\frac{I^2 \log \frac{r_2}{r_1}}{2\pi kt}(1 + c^2 H^2).$$

If k' is the conductivity of the disk in the magnetic field we may write the total rate of heat production when a radial current I is sent through it

$$\frac{I^2 \log \frac{r_2}{r_1}}{2\pi k' t}.$$

Thus

$$\frac{k}{k'} = \frac{\sigma'}{\sigma} = 1 + c^2 H^2 \quad \text{or} \quad \frac{\partial \sigma}{\sigma} = c^2 H^2.$$

In this expression σ is the specific resistance of the metal and σ' its effective specific resistance in the transverse magnetic field. Now according to this view the resistance of a conductor should always be increased by a magnetic field. It is known, however, that with some metals notably iron and nickel, the resistance is decreased in a transverse magnetic field. Furthermore, the increase of resistance calculated from this formula is very much less than the increase actually observed. In the thought that the change of resistance might be dependent on the geometrical form of the metal Mr. Lester has measured the effect of a transverse magnetic field on the resistance of a number of metals, using disks with a radial current.

His results are in good agreement with previous measurements made with wires and strips. For example, in the case of bismuth, using the same disk that was employed to measure the circular current he found, for a field $H = 5{,}000$, $\delta\sigma/\sigma = 0.16$. Now $c = 2 10^{-5}$ for $H = 5{,}000$, so that $c^2H^4 = .01$. It is thus certain that some other influence is effective in causing the main part of the change of resistance of a metal in a magnetic field; it is very probable that the field affects the molecular structure of the metal.

The interpretation of these results from the point of view of the electron theory of metallic conduction is unsatisfactory. I have worked out their theory[3] assuming free electrons in the metal that collide with the metallic atoms and obtained very simple expressions for the number of electrons in unit volume and their time between collisions. The numbers so obtained are of the same order of magnitude as have been obtained by other methods. But the difficulty of accounting for the difference in sign of the effect for different metals on any such simple theory indicates that if we are to hold to the electron theory of metallic conduction other forces than those resulting from collisions like those between hard elastic spheres must be supposed to act upon the electrons. The surprising thing is that so much can be explained by the simple theory of electrons when all such forces are neglected.

We have seen that the Corbino effect is, essentially, the same as the Hall effect. In its measurement and interpretation the Corbino effect has some important advantages over the Hall effect. In the first place it is not necessary to use the very thin films that are required to produce measurable Hall effects. And in the second place the absence of the free transverse boundaries render the interpretation of the Corbino effect simpler than that of the Hall effect.

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[3] *Philosophical Magazine,* XXVII., p. 244, 1914.

SOME RESULTS FROM THE OBSERVATION OF ECLIPSING VARIABLES.

By RAYMOND S. DUGAN, Ph.D.

(Read April 24, 1915.)

At Princeton we have been using for over ten years a stellar photometer devised by Pickering and similar to the one used for so many years to such good purpose by Wendell. This photometer has many virtues and but few vices. Its construction is such that the observer has the very comfortable conviction that nearly all the sources of systematic error he can think of are being rendered innocuous by the program of observation. In accuracy it is apparently excelled by the electrical photometers alone.

A large part of our researches at Princeton has for some time been the observational and theoretical study of eclipsing variables. From the beginning we were of the opinion that the patient distribution of observations repeatedly throughout the entire period of light-variation might very possibly bring us several facts to repay us for the great labor involved.

The first star subjected to this process was *RT* Persei.[1] 14,464 measures made during the years 1905–8, combined into a mean curve, showed at once the existence of a secondary minimum, 0.13 of a magnitude in depth, and with satisfactory distinctness a slight change in brightness between eclipses. This latter change was interpreted to mean that the two stars are ellipsoidal and brighter on the sides facing each other. An asymmetry, established with considerable certainty in the curve of primary eclipse, was found to prevail throughout the entire curve. Combining this with the knowledge of one component of the eccentricity derived from the observed displacement of secondary minimum toward the preceding

[1] See Contributions from the Princeton Univ. Obs., No. 1.

primary minimum, Shapley has recently explained this asymmetry as a Periastron effect—an increased brightness of the stars when nearest each other. There is another possible explanation which I shall consider in connection with the third star.

In 1909 the series of 18,384 measures of *z* Draconis was completed.[2] Evidence of a very shallow secondary minimum, only six or seven hundredths of a magnitude in depth, displaced slightly toward the following primary minimum, was clearly found. Ellipticity of figure and exchange of radiation were again demonstrated. These two effects have been abundantly verified in other cases.

The theoretical representation of the observations of both *RT* Persei and *z* Draconis just at the beginning and end of eclipse is a little unsatisfactory—the theoretical curve starts to drop more rapidly than the observed curve. This is possibly evidence that the stars are darkened toward the limb—like the sun.

It was hoped that the observations of *RV* Ophiuchi would not only demonstrate the existence of darkening toward the limb but would determine approximately the degree of darkening. But darkening seems to be very elusive sometimes. The observed secondary minimum is barely deep enough for the uniform solution, and a darkened solution requires a still greater depth. The well-determined primary minimum is strongly asymmetrical. The inter-radiation effect is about the same as in the other two stars, while the ellipticity is much greater. This latter fact when considered with the anticipation that the ellipticity effect would in this case be too small to detect—on account of the large distance between the component stars—is somewhat disconcerting. Then too there are several well-defined hollows in the curve—a conspicuous one just after primary and another just after secondary—and a long stretch before secondary when the star is much brighter than before primary. The only satisfying method of solving the curve seemed, therefore, to be a least square solution of the whole curve—a procedure hitherto avoided. The final theoretical curve, representing our present knowledge of the causes of light variation of these stars, is the result of the solution of forty-two equations with seven

[2] See Contributions from the Princeton Univ. Obs., No. 2.

unknowns. The probable errors are of satisfactory smallness, considering the amount of asymmetry.

It seems necessary in this case to face the fact of asymmetry unflinchingly. The secondary minimum gives no evidence of an eccentric orbit and the consequent possibility of a magnified periastron effect. The most conspicuous asymmetry is a greater brightness from middle of primary eclipse through to secondary than on the other side. A sine term of the first order with an amplitude of three hundredths of a magnitude takes care of the greater part of this. The existence of this sine term would probably indicate that the advancing side of the bright star is brighter than the following. If such were the case, then the loss of light during the early stages of eclipse—when the brightest part of the disk is being covered—and the gain of light right after totality would both be more rapid than would be the case if the disk were uniformly bright, as was assumed for the least square solution. The divergence from the theoretical curve of the well observed branches of primary minimum is in this anticipated direction and it is of about the right amount. A similar asymmetry has already been remarked in the curve of *RT* Persei and is probably also, at least in part, due to this cause. This suggested explanation is of course not new, but the evidence is apparently strong that the advancing side of the brighter component of some Algol variables is brighter than the following side. After this sine term is removed from the curve of *RV* Ophiuchi, there seem to be other changes in brightness of an amount small but seemingly guaranteed by the probable error.

In the system *RT* Persei, one star is one and one third times as large and five times as bright as the other; in *z* Draconis, one star is thirteen times as bright as the other but just about equal to it in size. The eclipse is very deep and nearly total. In *RV* Ophiuchi one star is twelve times as bright as the other but smaller. The brighter star is entirely hidden behind the fainter for about an hour. The two stars are farther apart than in the other two systems but they are apparently much more elongated.

During the seven years since completing the light-curve of *RT* Persei I have observed through an occasional primary minimum both visually and photographically. Recently I have observed two

secondary minima. The eclipses are now coming over forty minutes earlier than they are predicted by the elements determined from the original series of observations. This is very surprising in view of the accuracy with which the elements were determined. These elements were determined mainly from a large number of well observed minima grouped quite closely about two epochs about 700 periods apart. If the time of eclipse is fixed by the observations within a half-miniute in each of these two regions, then the period is known to one-tenth of a second. In cases where both branches of the minimum were continuously observed it seems hardly possible to change the observed time of any individual minimum by more than one or two minutes, and still represent the observations closely.

The photographic record of *RT* Persei, generously furnished me by Professor Pickering, showed that at —7,500 *P*, or 17½ years before the zero epoch, the eclipses were about 100 minutes late. The average period, then, is nearly a whole second shorter than the period determined from my original series of observations. This shorter period should have caused my observed minima to run off ten minutes from the predictions during the interval of 700 periods. This is intolerable. Beside my own observations, there are a good many observations by Wendell and several by Graff available. Of course a single estimated photographic magnitude is not nearly as accurate for determining the time of minimum as a series of photometric observations right through the eclipse.

Making now the correction to the shorter, average period, I have plotted the new residuals, and find that two periodic terms, one running its course in 12,000 eclipse-periods, or 27½ years, the other in one-third this time, or 4,000 periods, with coefficients of twelve and five minutes respectively, going through their zero values on the up grade together, fit the observations pretty well. The smaller period is of the order of magnitude of that to be expected from the revolution of the line of apsides caused by the observed prolateness of homogeneous stars. The amplitude is of the size to be expected from the smallest value of the eccentricity in accord with the observed shift of secondary minimum.

The important question, and one which is difficult to answer, is whether the time of the secondary eclipse shifts in either of these

periods. The revolution of the line of apsides in the shorter period would cause the time of secondary minimum to oscillate back and forth to an extreme of ten minutes before and after the midway point between successive primaries.

The evidence is both scarce and somewhat uncertain. The entire secondary eclipse amounts to a drop of but little over a tenth of a magnitude. An isolated photographic estimate of brightness is of little value here. Even from a continuous series of photometric observations, it is difficult to fix on the time of mid-eclipse within several minutes. My own observations, weighted according to the apparent certainty with which they determine the time of mid-eclipse, indicate rather strongly the shift in the time of secondary eclipse in the shorter of the two periods. The few observations by Wendell do not furnish any very strong evidence for or against this result. In no case were his observations carried through both branches of the eclipse, and consequently they do not determine the time of the eclipse with much accuracy. What disagreement there is, is in the same direction as in the observations of primary eclipse—for some reason the Wendell times of eclipse are nearly all earlier than mine. The evidence in hand at present points to a revolution of the line of apsides of *RT* Persei. I hope to observe occasional primary and secondary minima of this star during the next few years.

As a bi-product, I have determined the photographic curve from the Harvard observations and compared it with the visual curve of primary minimum. According to the observations, the eclipses in the two regions of the spectrum are of the same duration and the same depth, but the curves follow different paths. This is too strange a result to be taken very seriously, considering the paucity of the photographic material. I have, however, one minimum which I observed through a blue color screen made for the purpose. Through this filter the minimum was observed about 0.15 magnitude deeper than without the filter. So I conclude that the observations at the bottom of the photographic curve, which are few in number, are to be disregarded and the curve extended to the greater depth given by the color-screen observations. The difference in the character of the two curves indicates that when one star is in great part covered up, the light of the system is more reddish than when

they both shine undimmed. Either one star is redder than the other, or the eclipsed star is redder toward the limb than at the center.

z Draconis has been an equally interesting surprise. The average period is quite a little longer than was supposed. Some time ago it shortened up with great rapidity. The top and bottom of this sharp decline are well determined by observations from quite a variety of sources. The two sine terms combined in this case have periods of 7,200 and 2,880 eclipse-periods and nearly the same coefficients as in *RT* Persei—ten and four minutes respectively. The prolateness and eccentricity of *z* Draconis are about the same as those determined for *RT* Persei.

The secondary minimum of *z* Draconis is only 0.06 magnitude—half as deep as that of *RT* Persei; the observations of the secondary minimum are few and were all taken within a brief interval, and they furnish very little evidence. This star must also be kept under frequent observation. When observing this star with the 23-inch it requires a determined effort to see it at all when in the middle of its deep eclipse.

The greater depth of the photographic eclipse comes out very nicely in the case of *z* Draconis. As the eclipse increases, the light from the star becomes redder and redder. At deepest phase more than half the light is known to come from the fainter star. It is apparently much redder than its far brighter companion, a fact which is doubtless to be expected.

Lastly, in reducing the observations of *RV* Ophiuchi I found it necessary to predict the minima with a sine term of about 1,600 periods, and of small amplitude. The photometric history of *RV* Ophiuchi is short and incomplete compared with that of *RT* Persei and *z* Draconis, and no conclusions can safely be drawn from this result.

Princeton University,
April, 1915.

SOME PRESENT NEEDS IN SYSTEMATIC BOTANY.

By L. H. BAILEY.

(*Read April 23, 1915.*)

If an editor were to survey the families and genera and species of the vegetable kingdom, he would find himself making comparisons and drifting to conclusions respecting the character of the systematic work and the worth of various contributions. Many of these conclusions he might not be able to analyze. They might be very much in the nature of impressions, and yet they might be felt so strongly as to be convictions. It is a vast field that his oversight would cover, and the bases of comparisons would be of the most various kinds, yet the convictions in very many cases would be concrete. It may be well to consider for the moment some of these possible convictions, of course in no spirit of captiousness, but to bring other points of view on some of our common problems, even though these points of view may not always be capable of direct application.

Very likely, his first feeling would be a consciousness of the great variety in the methods of the monographs. The systematic work is rapidly specializing, and the specialists make their own criteria. The result is a marked diversity in the work, which all the efforts at standardization do not very much control. Probably, Bentham and Hooker's "Genera Plantarum" is the last of the comprehensive works to be brought to a completion by a single person or by two or three persons working as one. This is succeeded by the editorial work of Engler and Prantl in "Die Natürlichen Pflanzenfamilien," and later in more detail by Engler in "Das Pflanzenreich." Floras of countries and regions tend more and more to be constructed editorially, with contributions by specialists. All this results perhaps in closer work in the specialties and the details, but it may lack in coordination and in the balancing of the parts.

Probably all the larger conclusions by our hypothetical editor would be derived from this general situation. No longer do we have the controlling authority of one man, holding the work steady and maintaining a homogeneous method. I well remember a remark that Asa Gray made about his Compositæ, on which he had worked so long and so lovingly, seeing the end of his time and foreseeing the change of his method. I remember also that in those days I was somewhat violently interested in nomenclature and I proposed to publish on it; but Gray gently dissuaded me: it was some years before I understood why.

A Situation in Nomenclature.

In proportion as we lose the influence of a single controlling personality, or of a few personalities working in an understood harmony, do we resort to arbitrary and conventional methods of codification. This is well illustrated in the convulsions in nomenclature in recent years. In this country, for example, with the passing of Gray, we began to give up the combination of two words as the name of a plant, and to substitute the oldest specific name brought down through any number of genera. Intrinsically, one method is as good as the other, but we sought to arrive at uniformity by rigidly adopting one of them. A train of difficulties has followed this and other innovations, and instead of finding ourselves in full harmony of action, with one uniform practice in nomenclature, we have two or three or several practices, and to a considerable extent each worker making his own. The present situation in nomenclature is a vivid illustration of the failure of arbitrary means of standardization. The situation also has a social significance, as I shall attempt to suggest.

The probability is that we should have arrived at our destination sooner and with no greater confusion if we had allowed the situation to work itself out without formal regulation, recognizing more fully the principle of usage which in the end controls all language. We have probably made a mistake in endeavoring to substitute arbitrary priority for stability; at all events, we might have saved ourselves the very amusing exercise of upsetting a well established name for the purpose of substituting an older name in order that

we might make the name stable. It looks now as if usage were after all to control in the end, and in some regards quite independently of arbitrary regulations. The principle of undeviating priority has not yet controlled for any length of time in the development of language. It is a false premise.

I am not now arguing for a return to any older or prior method, nor in challenge of any current practice, and certainly not in criticism of any group of workers, for we shall probably outgrow our conventionalities sooner by working with them rather than against them. But I must protest, as I have protested many times before, against the assumption that the names of plants belong to botanists to do with them as they will. This is only another way of saying that these latinized names of plants are rightfully a part of language and are not mere formulæ or symbols to be used only by insiders. We desire that the public shall use this language. We publish our manuals with this purpose. We try to make plant books simple, that they may be popular. We take pains to spread the knowledge of plants and thereby to promote the love of nature. There are thousands of persons who sell plants, and the names become established in trade and represent commercial values. These values cannot be shifted readily from name to name; and if one makes a plea for correct nomenclature in plantsmen's catalogues and lists, one receives the reply that it is scarcely worth the while seeing that the names change so frequently. The custom of shifting the names is undoubtedly directly responsible for much of the disregard of new nomenclature on the part of dealers; and we must remember that the use of these kinds of names among the people is probably promoted more by the plant dealers than by the botanists. I judge that the botanists have not yet succeeded in securing the active and free cooperation of this great class of people.

Of course we are to recognize that much of the change is inevitable, that, in fact, it is a consequence of new and closer studies of the groups, resulting in a clearer understanding of generic and specific limitations. This is a contribution to knowledge which everyone must accept. But there is a class of changes which does not have this justification. I am conscious, in making inquiries,

that the first thought of some particularists appears to be a desire to see whether it is possible to change the names.

Nor am I yet ready to leave this subject. From a successful and sincere public lecturer, who is trying to lead the people to a knowledge of animals and plants, I had a request for aid containing the statement that he could devote only a little time daily "to the study of Latin and I want to get only a sufficient knowledge of it to enable me to know why the gipsy moth is called (*Porthetria dispar* L.) and whether *Raphamus raphanistrum* means a plant, an insect or a tribe of elephants." This person, of course, had not had a college training in these particular subjects, but he is not ignorant or inattentive. He writes that he has about 2,000 bulletins, many bound volumes and a special cyclopedia, nearly all of which material is classified, using a card-index. "It has taken a lot of work to do this but as I can spare from farm labor only about an hour each day for study I find the index is a great time saver by showing me just where to find what I want." This man will accomplish much with his methods of contact. But consider the position of this man if to a complicated system of nomenclature we add a continuous tendency to change; and I think it is fairly our obligation to consider his position.

When we feel within us the desire to change the names of genera and groups, let us think well of this man and his carefully considered hour,—what it would mean to him in cross-referencing, in indexing, in the readjusting of his work. If it is to bring new knowledge that we cannot so well record otherwise or indispensable definitions, very good; but the burden of proof always rests on the new name. The work with names is fascinating, even captivating, and every change identifies the worker with it; but we are not to forget that some of this work is likely to be of the kind that, in other fields, might be called pedantry.

Bear with me further while I call your attention to the fact that we are not only changing our plant names with apparent disregard of the users of them, but that we are also making them more complicated. To the name of the plant,—genus and species,—we add the authority. We now omit the punctuation and thereby make the

author in effect a part of the name. When the combination of two words was held to constitute the name of a plant, the author of the combination was sufficient for identification; but with the single-word system we carry the author of both the original specific name and of the new combination, and the whole becomes something like a complicated formula. This is a convenience to the worker with plant names, but he is not the only party concerned; his needs may be served in the citation of the synonomy. His obligation to the public is to present the simplest possible name and the least involved. If the history is to be retained in the name-compound, where may we not stop and how complicated may our formulæ finally become? We may in time evolve a phraseology, or an algebraic form, as complicated as some of the pre-Linnæan customs. We are really confusing two things,—nomenclature and bibliography. We should separate citation from nomenclature. We have no right to inflict the public with our taxonomic book-keeping.

There are three pressing needs in our present systematic botany, as I see it. One of these needs I have now tried to suggest, which is the urgency to subordinate the nomenclature question. This is specially important in a democracy, where we desire to give all qualified persons equal chance, where we are supposed to remove hindrances and arbitrary domination by central authorities and to allow the people to express themselves freely. The public has real rights in the names of plants. Soon we must stop playing with names.

A Situation as to Species and Genera.

The oversight that we assumed in the beginning would undoubtedly discover other interesting situations in our systematic work. What these comparisons might be would depend, of course, on the particular person who made them; but in respect to the American work, with which at the moment we are mostly concerned, any person could not fail to admire the quality of the monographs and lesser contributions. Although systematic botany may occupy a subordinate place in our teaching, it is receiving extensive and very expert attention both from amateurs and from those attached officially to the great collections, and the published work is such as to

give us much pride. Ability of a high order continues to express itself in this field.

We have noted the tendency to specialize. Persons become expert in certain detached groups of plants. We become most skillful in detecting the differences that may distinguish species, but it may be doubted whether we are equally skillful in bringing together the agreements that may formulate genera. We seem now to be discovering separateness. It does not follow that one who has nice judgment on species necessarily has equal authority on genera. The tendency to break up our old groups into many genera, is apparently the result of the application of the species-habit. It is a great question whether the method of separation is the proper one to apply equally in these two kinds of cases.

Perhaps we cannot hope for much result in the standardizing of the species-conception by our methods of herbarium work, but it ought not to be difficult to arrive at some kind of an agreement on genera. We may well consider the advisability of being progressive in searching out the ultimate specific units—so far as there are such units—at the same time that we hold a conservative attitude on genera, for we can scarcely assume that there are ultimate generic lines. Thereby we might make a truthful presentation of the vegetable kingdom at the same time that we avoid vast changes in nomenclature.

A Situation as to the Living Material.

With the needful specialization of the systematic work, we find ourselves with very unequal treatment in the different groups. This inequality is perhaps the most outstanding characteristic of our present phytographical publication. It is impossible at present to compile a general work with any clear approach to uniformity of handling in the different genera and families. This is due in part to the fact that some of the groups have been recently worked over whereas others still retain a traditional treatment. Nor is it desirable that there shall be rigid codification on genera, for we need the judgment of different workers and this necessarily leads to non-uniformity; the specialist is entitled to his method; and yet the inequalities in interpretation appear to be so great in many cases as to amount to inharmony and even to confusion.

While there is more hope in the standardizing of genera than of species, it is within the possibilities to arrive at some kind of agreement on specific values, but this is not to be expected as a result of codification or regulation: it must be a real agreement by men who are brought together on a new kind of study of a common line of problems.

As I have already indicated, I would not expect or even desire a dead uniformity of treatment in any range of systematic work, and least of all in species. It would be a great misfortune to lose the expression of personality in even such formal work as this. But there is need of a closer understanding as to the essential facts in the treatment of the members of a genus. If one were to look over *Erythrina,* for example, one would find about 50 species recognized, native in warm countries in the two hemispheres; and while there is much uncertainty as to the characters of given species, one would not find very wide disagreement between the different authors. If next one were to look on *Eschscholtzia,* one would find a wholly different state of things, notwithstanding the fact that this genus is confined to western North America. Gray saw about a dozen species in this genus; Greene, with more material to work on, saw 112 species; and Fedde sees 123. Jepson, who has studied them with care in the field, is not able to see a great number of species, although he finds numberless seasonal and other forms; and he does not see much hope in solving the *Eschscholtzia* puzzle by the usual study of herbarium material but rather by "combined field and cultural studies."

And here is the particular suggestion I desired to make in the writing of this paper,—that a few groups be worked out very carefully by growing the plants under observation and as far as possible under conditions of control and always, of course, in comparison with living feral material. Such studies might require some years, even in a relatively small group: very good—the results would be all the more convincing. If a half dozen groups could be worked over in this way, with discussion of the living material by standing committees of some recognized association, we should very likely arrive at a basis of judgment such as the present collecting and inci-

dental field notation and indoor study of dried material can never give us. The conclusions,—or the points of view, if conclusions were impossible,—would be invaluable in bringing us to an understanding and therefore to a substantial agreement on some of the matters that are now most perplexing us. This is now the greatest need in systematic botany.

This means that we should now study life histories with the purpose to apply the knowledge in systematic work. We shall come to the end in due time of the inventory process in describing new species. After a time we shall consider it to be scarcely worth the while to carry the separative process very much farther, and we shall then undertake a synthetic process of building up the forms into species-values. The current studies of variation and of plant-breeding are bringing us to a new point of view: it is now time that we begin the incorporation of these methods into our systematic work.

Ithaca, N. Y.,
April 23, 1915.

THE VARIABLE STARS *TV, TW, TX* CASSIOPEIÆ AND *T* LEONIS MINORIS.

By R. J. McDIARMID.

(*Read April 24, 1915.*)

The four Algol variable stars *TV, TW, TX* Cassiopeiæ and *T* Leonis Minoris have been under observation by the writer for the last three years with the polarizing photometer attached to the 23-inch equatorial of the Princeton Observatory.

The total number of measures made on the four systems is over 35,000, distributed among the four stars as follows, *TV* 9,920, *TW* 13,728, *TX* 8,486 and *T* Leonis 3,792. The light curves of the first three are well defined, while the observations on the last system are not so complete. The periods of the light variation with the exception of *TV* Cass. have been determined from my visual observations combined with photographic measures kindly sent me by Professor Pickering, of Harvard.

The systems will be discussed in slightly different order than the above, the more important left to the last.

The system *TW* Cass. has been observed by other astronomers, and notes published pronounced it as irregular in its variation, later Zinner found it regular in its variation and of the Algol type with a period $1^d\ 10^h\ 16.6^m$. From the discussion of the Princeton observations I found that the period was double the published period and instead of one eclipse there were two differing by 0.05 magnitude. The double period is confirmed by the three observed phenomena, 1st, the difference in depth of the two minima of 0.05 mg.; 2d, the interval from primary eclipse to secondary is 7.8 minutes longer than from secondary to the following primary; 3d, the primary eclipse is 36 minutes longer in duration than the secondary. It is from the knowledge of the last two facts that we are able to determine both components of the eccentricity—the quantities e and (longitude of periastron). The period is 2 days, 20 hours, and

33.6 minutes and the two eclipses have a depth of 0.62 mg. and 0.57 mg. respectively. From a discussion of the light curve following the theory as outlined by Professor Russell in *A. J.*, 36, 5; 36, 1 results were obtained giving the dimensions of the system in terms of the radius of the orbit. It was found that the two stars were of nearly the same size and had the same surface brightness.

In the case of *T* Leonis Minoris as in *TW* Cass. we have two minima, they are however of very different depth, the primary having a loss of 2.46 magnitudes while the secondary has only 0.05 magnitudes. The period is 3 days, 0 hours, 28 min., and 38.0 sec., and is accurately known. Combined with the visual observations I have used the Harvard photographic measures as far back as 1889, and have been able to establish a definitive period. The observations are not so complete as in the other systems, the length of the period being so nearly three days; also weather conditions at special times have entered largely into this.

From a study of the light curve along the lines of the eclipsing theory it has been found that the stars are of nearly the same size but are very different in surface brightness, the ratio being 1 : 18.

The third system *TV* Cass., whose period, $1^d\ 19^h\ 30^m\ 11.7^s$, has long been known, having been observed by Ashbury and Yendell, was placed under observation in October, 1913, at Dr. Shapley's suggestion. At that time nothing was known about the secondary eclipse. From my observations it was found that a secondary eclipse of 0.09 magnitude did really exist, coming 21 minutes before the time of mid period. The orbit of the system like that of *TW* Cass. is eccentric, but in this case the components of the eccentricity can not be separated.

In the two previous stars it was found from the light curve that the stars were of constant brightness between eclipses. The light curve of *TV* Cass. is somewhat different as there seems to be a gradual rise in the curve between primary and secondary eclipse which corresponds to an increase in brightness of the system. The explanation is, that the radiation of the bright star on the side of the fainter one as they approach the time of secondary eclipse tends to brighten its surface and thus give rise to the phenomenon observed in the light curve. From a study of the light curve it was found

that the fainter star was twice as bright on one side as the other. The stars are nearly equal in size with a ratio of surface brightness of 1 : 5.5. In this system the depth of the primary eclipse is 1.05 magnitudes and its duration a little over 6 hours.

The last system, *TX* Cass., is the most interesting of the four stars treated here. It was announced some years ago as being an irregular variable; later its period was given by Zinner with the note, that the period was probably changing. It was partly on account of these published notes that a thorough study of the light curve of the star was carried out. Owing to the nature of the variation the star has proved to be a difficult system for photometric study. The eclipses, primary and secondary, which undergo a loss of light of 0.54 and 0.33 magnitudes respectively and last over 18 hours, are difficult to observe, in fact it is impossible to obtain a complete minimum on any one night even during the long nights of winter. The Harvard photogarphic measures have again proved to be of extreme value and by combining them with the visual observations I was able to establish a definitive peroid. The period is 2 days, 22 hours, 14 min., and 41.7 sec.

In the systems so far discussed the stellar disc was considered of uniform surface brightness. Assuming this to be the case with the system *TX* Cass. it was found that the observations could not be represented at all satisfactorily; the deviations were in many cases three times the probable error. On the other hand assuming the stellar discs to be similar to the sun bright at the center and decreasing in brightness toward the edge, a very satisfactory representation of the observations was found. The hypothesis of darkened discs seems to be the correct one as it is confirmed by the nature of the eclipses; the secondary eclipse is total with a constant phase of six hours while the primary eclipse has no constant phase and the curve is distinctly round bottomed showing that the variation is continuous. This condition would exist with darkened discs in case of an annular eclipse, and since the secondary is total our natural and legitimate conclusion is that the primary is annular. The system *TX* Cass. seems to offer very strong evidence in support of darkening toward the limb in stellar systems.

The light between eclipses does not remain constant; the light curve is distinctly bowed up, showing the stars are elliptical in shape and have their greatest brightness when we see them broad side on. This is the condition midway between eclipses. From the study of the light curve it was found that the stars are very different in size, with the stars nearly of the same brightness having a ratio of 1 : 1.5. The ellipticity of the stars can best be shown by giving their dimensions expressed in terms of the radius of the orbit.

	Major Axis.	Minor Axis.
Big star	$a_1 = 0.567$	$b_1 = 0.519$
Small star	$a_2 = 0.295$	$b_2 = 0.270$

The stars in this system are very close together.

AN INTERPRETATION OF STERILITY IN CERTAIN PLANTS.[1]

By E. M. EAST.

(*Read April 23, 1915.*)

It is obvious that it is impossible to investigate the cause of sterility in hybrids by the pedigree culture method when such sterility is complete. Occasionally, however, one finds hybrids which are not wholly sterile. Such is the case in the historic cross, *Nicotiana rustica* L. × *Nicotiana paniculata* L. This hybrid holds an enviable position in experimental botany, since it was the first artificial hybrid to be studied. It was made by Kölreuter in 1760 and was studied by him for several years by means of back crosses with each parent.

This cross I repeated in 1909, using as the *N. rustica* parent a small variety *N. rustica humilis* Comes obtained from Dr. Comes through the kindness of Dr. D. G. Fairchild. It has now been studied through five generations both in the field (general morphology) and in the laboratory (histology and cytology). The essential points noted, as I see them, are as follows:

Two species giving extremely uniform progeny when selfed have, when crossed, given an intermediate F_1 population as uniform as themselves, and an inordinately variable F_2 population.

The germination of F_2 seeds varies in different samples from 20 to 60 per cent.

Practically no two F_2 plants are alike, and the parental forms are recovered once in every 100 to 200 F_2 plants.

In F_1, from 1 to 6 per cent. of the ♀ gametes are functional. It is impossible to determine the percentage of viable ♂ gametes formed from the pollen mother cells, but from 2 to 6 per cent. of the

[1] It is impossible to reproduce the photographs shown by means of lantern slides, but an illustrated paper giving the details of the investigation is to be published shortly.

pollen found is morphologically perfect. The maturation difficulty in spermatogenesis is largely at the first spermatocyte division.

F_1 plants are as fertile *inter se* as in back crosses with either parent.

Segregation of determiners for fertility occurs in F_1, so that by recombination some perfectly fertile plants are obtained in F_2.

Nearly all fertile F_2 plants selfed give only fertile progeny. Occasionally a fertile F_2 plant selfed may give a slightly non-fertile daughter.

Numerous combinations that should be possible in F_2 are omitted in the population obtained. Combinations approaching *N. rustica* seem to be more frequent than those approaching *N. paniculata*. Many more homozygous combinations occur in F_2 than might be expected.

Perfectly fertile plants giving perfectly fertile progeny, heterozygous for many allelomorphs, do occur in F_2.

No more than a very general formal interpretation of these facts can be made at present, but assuming that the chromosomes carry the hereditary character determiners, and that these react with the cytoplasm under proper environmental conditions to build up the soma. attention is called to the following possibilities of satisfying the conditions imposed by the data.

1. There is selective elimination of F_2 zygotes.

2. There is no evidence of selective fertilization. (I infer this from the fact that F_1 plants are as fertile *inter se* as in backcrosses.)

3. The selective elimination of non-functional gametes that must occur in F_1 and the recombinations of functional gametes that give different grades of fertility in F_2 cannot be interpreted by a Mendelian factorial notation without subsidiary assumptions, but possibly may be the result of one of the two following hypotheses:

(*A*) Through multipolar spindles, mating of non-homologous chromosome pairs at synapsis, or other mitotic aberrations at the reduction division, the 24 chromosomes characterizing each of the two species may be irregularly distributed at gametogenesis. If some of these irregular gametes may function, the majority of the experimental data are satisfied, but there are reasons which there is not time to consider which make this scheme improbable.

(*B*) On the other hand the facts may be interpreted without assuming irregularities of chromosome distribution if (1) there is a group of chromosomes in each parent that cannot be replaced by chromosomes from the other parent; if (2) there is a group of chromosomes from each parent, a percentage of which may be replaced by chromosomes from the other parent, but where functional perfection of the gametes varies as their constitution approaches that of the parental forms; if (3) there are other chromosomes that have no effect on fertility and therefore can promote recombinations of characters in the progeny of fertile F_2 plants; if (4) a naked male nucleus entering the normal cytoplasm of the egg in the immediate cross can cause changes in the cytoplasm that will affect future reduction divisions; if (5) this abnormally formed cytoplasm is not equitably distributed in the dichotomies of gametogenesis in the F_1 generation; if (6) it follows from (4) and (5) that F_2 zygotes may be formed which are less perfect in their gamete forming mechanism than those of the F_1 generation; and if (7) the heterotypic division of gametogenesis does not necessarily form two cells alike in their viability.

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Harvard University.

PROCEEDINGS

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ADDITIONS TO THE FAUNA OF THE LOWER PLIOCENE SNAKE CREEK BEDS (RESULTS OF THE PRINCETON UNIVERSITY 1914 EXPEDITION TO NEBRASKA).

BY WILLIAM J. SINCLAIR.

(*Read April 24, 1915.*)

One of the objects of the Princeton University 1914 Geological Expedition to Nebraska was to acquire, if possible, fossil bones from the Lower Pliocene Snake Creek beds of Sioux County, partly to fill out the exhibition and study collections of the Department of Geology, which were lacking in Pliocene vertebrates, and, partly, to obtain some additional light on the fauna of the Great Plains region in Lower Pliocene time, with the purpose of establishing a broader basis for the correlation of Continental Interior and Pacific Coast Tertiary deposits. In both respects the expedition was thoroughly successful, which I attribute, in large part, to the enthusiastic support of my assistants, Messrs. A. C. Whitford, of Lincoln, Nebraska, and Mr. Charles Barner, of Agate, and to the kindness of our temporary neighbors, the various ranchmen on whose ranges the bonebearing deposits lie.

The Snake Creek beds were named and described by Matthew and Cook,[1] and reference should be made to their paper for details not brought out in the pages which follow. The four exposures worked by the Princeton party lie within the limits of the Whistle

[1] "A Pliocene Fauna from Western Nebraska," *Bull. Am. Mus. Nat., Hist.*, N. Y., Vol. XXVI., Art. XXVII., pp. 361–414, 1909.

Creek quadrangle, south of the sandhills on the divide between the Niobrara and the North Platte rivers, in draws at or near the heads of Dry Spotted Tail Creek, Spotted Tail Creek and Snake Creek, as follows: Loc. 1000A, T. 26 N., R. 55 W., Sec. 31 (N. E. ¼); Loc. 1000B, same township and range, but in the southeast quarter of Sec. 33; Loc. 1000C, T. 25 N., R. 55 W., Sec. 3 (S. E. ¼ to middle of section); Loc. 1000D, T. 25 N., R. 54 W., Sec. 2 (N. E. ¼). Of the four, Loc. 1000C, to which the attention of Messrs. Whitford and Barner was called by Mr. John Weir, before my arrival in the field, was particularly productive, yielding some of our best material.

The Snake Creek beds comprise unconsolidated, water-worn gravels, clean, cross-bedded, round-grained sands sometimes streaked with magnetic, and a mortar-like, gray-white material, sometimes in angular fragments and sometimes in cobbles or boulder-like masses, resting with marked erosional unconformity on the Middle Miocene Sheep Creek beds. Rolled pebbles of granite, quartzite, etc., indicate water transportation from the crystalline rocks of the mountains farther west, probably some of the sand is windborne, but a large part of the Snake Creek matrix has not been transported far and consists, sometimes, of subangular fragments resembling in appearance dried mortar, and, sometimes, of gravels, cobbles, and lárge masses of more or less indurated clay or silt, evidently represented the harder portions of the Sheep beds through which the Snake Creek channels were cut. Many large, slightly rounded masses of Sheep Creek sediment incorporated in the Snake Creek sands and gravels are quite incoherent and could not have stood thorough saturation with water, not to mention transportation to any considerable distance. I think they were derived from the caving of undercut banks along channels incised in the Sheep Creek. Water-worn fragments of silicified wood are common, but are not necessarily remains of a forest contemporary with the Lower Pliocene fauna. Most of it, if not all, is *remanie* material.

The stratification is lenticular, water-worn gravels giving place laterally to cross-bedded sands and jumbled masses of clay boulders. Either gravels, sands or mortar-like fragments may rest with clean sharp contact on the eroded surface of the Sheep Creek, the irregu-

larity of which is increased by land sliding occuring along the sides of the draws where the exposures are found, but much of it is due to changes in the slope of the channel-beds in which the Snake Creek deposits accumulated. Upward, the formation merges into wind-blown sands and silts which cover the prairie top, and it is not always possible to distinguish between them, as bones sometimes occur in the lower layers of the sand above the level of the typical Snake Creek gravels.

Exposures, when found, are along the sides of the draws which have cut down through the Snake Creek beds into the underlying Sheep Creek, and are usually more or less obscured by wind-blown sand overgrown with grass and weeds, so that little in the way of fossils can be seen at the surface except an occasional weathered bone fragment on the bare spots between grass clumps. Occasionally, a larger ungrassed area of sand and pebbles may show a few horse teeth, a jaw fragment or two or the ends of some broken limb bones. All collecting was done by stripping off the surface sod and exposing the Snake Creek-Sheep Creek contact wherever the greater abundance of gravel and bone fragments suggested the presence of a productive "pocket" or lens of bone-bearing gravel. If the preliminary prospecting seemed to warrant further excavation, a large area was cleared and the bank cut back to a vertical face which was worked by undercutting at the level of the contact just mentioned. This was kept up until the productive gravel was exhausted or the repeating caving of the heavy top burden of sand made further work both laborious and dangerous.

The bones are remarkably well preserved, mostly black or of a dark color, and occur in both the gravels, sands and mortar-like conglomerate, becoming scarce as the sand gets clean or the number of clay boulders and cobbles increases. They are all more or less abraded, sometimes by water wear, at other times manifestly by wind-blown sand,[2] and vary in character from rolled bone pebbles to complete skulls. Hardly ever is there association of adjacent parts. Occasionally a *remanie* fossil, washed out of the Sheep

[2] The type skull of *Protolabis princetonianus* sp. nov. was found in soft sand, lying on the left side with the front of the skull tilted downward. The arch and back of the skull on the upper (right) side are pared down to a common level in a manner suggesting sand-blasting.

Creek, is found, but with this exception the bones seem to have been introduced directly into the streams which transported the Snake Creek gravel and, apparently, represent the fauna of the immediate vicinity, as frail teeth and delicate skull and jaw processes remain unbroken, suggesting that the bones have not been moved far. As will be seen by an examination of the Whistle Creek Quadrangle, our collecting localities are somewhat widely scattered and may not all represent the deposits of a single stream, possibly are not all strictly contemporaneous, but as our large collection from locality 1000C contains practically the same forms as are found in the remaining less fossiliferous localities, there is every reason to regard the fauna as a unit. So far as determined, the Snake Creek beds have yielded the following association of forms, those marked (*A*) being preserved in the American Museum, New York, (*P*) in the Geological Museum of Princeton University and (*C*) in the private collection of Mr. H. J. Cook, of Agate, Nebraska.

Dogs.

Amphicyon amnicola (*A*).
Amphicyon sp. indet. (*A*).
?*Amphicyon* sp. indesc. (*P*).
Aelurodon haydeni validus (*A*).
Aelurodon saevus secundus (*A*).
Aelurodon cf. *wheelerianus* (*P*).
Aelurodon sp. div. indet. (*A, P*).
Tephrocyon hippophagus (*A, P*).
Tephrocyon cf. *temerarius* (*A*).
Tephrocyon cf. *vafer* (*A, P*).
Tephrocyon mortifer (*C*).
Tephrocyon sp. maj. (*A, P*).
?*Cyon* sp. (*A*).

Civet-cat.

Bassariscus antiquus (*A*).

Mustelines.

Brachypsalis pachycephalus (*P*).
Brachypsalis obliquidens sp. nov. (*P*).
Martes glareæ sp. nov. (*P*).

Cats.

Pseudælurus near *intrepidus* (*P*).
Cat, non-machærodont (*P*).
Machærodont cat, gen. indet. (*A*).
?*Felis* cf. *maxima* (*A*).

Rodents.

Mylagaulus cf. *monodon* (*A*).
Dipoides curtus (*A, P*).
Dipoides tortus (*A*).
Hystricops cf. *venustus* (*A, P*?).
Geomys cf. *bisulcatus* (*A*).

Edentates.

Megalonychid, gen. et. sp. indet. (*A, P*).

Rhinoceroses.

Teleoceras sp. (*A, P*).
Aphelops sp. (*A, P*).
?*Cænopus* sp. (*A*).

Horses.

Archæohippus sp. (*P*).
Parahippus cf. *cognatus* (*A, P*).
Hypohippus cf. *affinis* (*A*).
Hypohippus sp. (*P*).
Merychippus cf. *insignis* (*A, P*).
Merychippus close to *calimarius* (*P*).
Hipparion cf. *occidentale* (*A, P*).

Hipparion gratum (*A, P*).
Hipparion cf. *affine* (*A, P*).
Protohippus cf. *placidus* (*P*, probably *A*).
Protohippus near *perditus* (*P*, probably *A*).
Pliohippus cf. *mirabilis* (*P*).
Pliohippus sp. div. (*A*).

PECCARIES.

Prosthennops cf. *crassigenis* (*A*).
Prosthennops sp. (*A, P*).

OREODONTS.

Merychyus (*Metoreodon*) *relictus* (*A*).
Merychyus (*Metoreodon*) *profectus* (*A, P*).
Merychyus (*Metoreodon*) sp. (*A, P*).
Pronomotherium siouense sp. nov. (*P*).

CAMELS.

Protolabis princetonianus sp. nov. (*P*).
Pliauchenia (*Megatylopus*) *gigas* (*A, P*).
Alticamelus procerus (*A, P*).
Alticamelus sp. div. (*A, P*).
?Procamelus sp. div. (*A*).

ANTELOPES AND DEER.

Dromomeryx whitfordi sp. nov. (*P, A*).[3]
Drepanomeryx falciformis gen. et sp. nov. (*P*).
Cervus sp. (*A, P*).
Blastomeryx elegans (*A*).
Blastomeryx cf. *wellsi* (*A*).
Merycodus necatus sabulonis (*A, P*).
Merycodus cf. *necatus* (*A, P*).
Merycodus sp. div. (*A, P*).

BOVIDS.

Neotragocerus improvisus (*A, P*).
Bovid gen. indet. (*A*).
Bison sp. (*A*).

MASTODONS.

Gomphotherium sp. (*P*).
?Mastodon sp. (*P*).

BIRDS.

Aquila danana? (*P*).[4]
Buteo near *borealis* (*P*).[4]

REPTILES.

Crocodile vertebra (*P*).
Lizard jaws (*P*).
Huge land tortoise (*A, P*).

OF UNCERTAIN POSITION.

Part of large mammal jaw (*P*).

The collections obtained by the Princeton expedition have greatly increased the number of Miocene genera represented in the Snake Creek fauna. *Archæohippus* excepted, *Brachypsalis, Pseudælurus, Pronomotherium, Protolabis* and *Dromomeryx* have species in the Upper Miocene, distinct, but not strikingly different from, their Snake Creek successors, rather increasing the close relationship of the fauna with that of the Upper Miocene previously commented on by Matthew and Cook. Additional Pliocene elements are far

[3] *Palæomeryx* sp. of Matthew and Cook.

[4] Represented in the Princeton collection by a fragment of the tarso-metatarsus. Determinations by Dr. Loye Holmes Miller.

less abundant. Perhaps the new horned artiodactyl, *Drepanomeryx*, presenting a type of horn-core not hitherto known in North America, and a mastodon apparently allied to *Mastodon americanus,* may be regarded as belonging to this category. The conception of old and new faunal elements should not be unduly emphasized, because, as our exploration of the Snake Creek beds plainly shows, we do not yet know the extreme upward range in time of a number of Upper Miocene genera and can merely say of the new, supposedly Pliocene, forms that this is their first appearance. A suggestion regarding climatic conditions may be found in the presence of crocodiles and huge land tortoises, the latter rivalling in size those of the Galapagos Islands, indicating, perhaps, that the approaching chill of glacial times had not yet exterminated these cold-blooded types.

DESCRIPTIONS OF NEW GENERA AND SPECIES.

AELURODON sp. compare WHEELERIANUS?

The left ramus of a lower jar with $p_{\overline{4}}$ and $m_{\overline{1}}$ and alveoli for the remaining teeth (No. 12068 Princeton University Geological Museum, collecting locality 1000C) is referable to an *Aelurodon* of about the size of *A. wheelerianus,* from the type of which it differs in the greater length of $p_{\overline{4}}$-$m_{\overline{1}}$, the shorter jaw and the closer crowding of the premolars. It is either too small or too large to be referred definitely to any of the described species of *Aelurodon,* but is hardly complete enough to be made a new specific type.

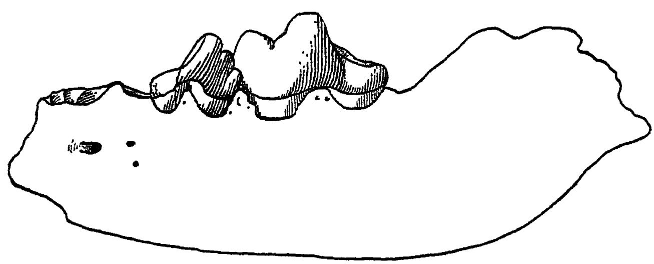


FIG. 1. *Aelurodon* sp., compare *wheelerianus?,* left ramus, side view, No. 12068, two thirds natural size.

?AMPHICYON sp. indesc.

A huge canid, possibly an undescribed species of *Amphicyon,* is represented in the Princeton Snake Creek collection by the right

ramus of the lower jaw, an ulna and some other bones, of which the lower jaw (No. 12078 Princeton University Geological Museum, collecting locality 1000C) is here figured to give some idea of its size and proportions. The fragment retains alveoli for the canine, four double-rooted premolars and the sectorial molar. The first and second premolars are separated from each other by a short space, and from the canine and first molar by long diastemata, whlie the rest of the dentition is in close series.

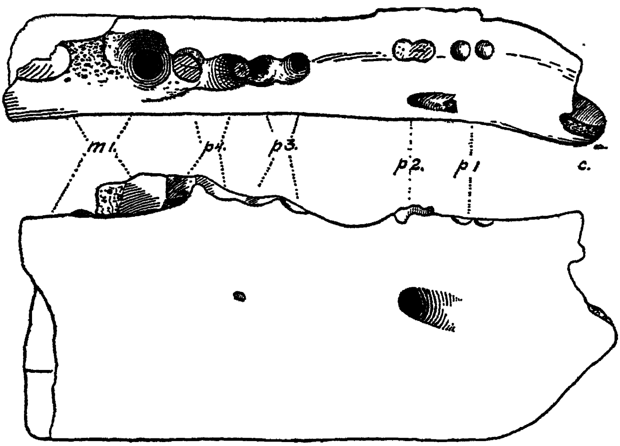


FIG. 2. ?*Amphicyon* sp. indesc., No. 12078, right ramus of the lower jaw, side and top views, one half natural size.

BRACHYPSALIS OBLIQUIDENS sp. nov.

Type No. 12070 Princeton University Geological Museum, collecting locality 1000C, the left ramus of the lower jaw with $p_{\overline{2}}$-$m_{\overline{2}}$ and alveoli of the canine and first premolar (Fig. 3). This is a decidedly larger, deeper-jawed, heavier-toothed species than *Brachypsalis pachycephalus,* with the anterior premolars placed very obliquely to the tooth-row and all the teeth closely crowded. It is of about the same size as *Paroligobunis* (*Brachypsalis*) *simplicidens* from the Lower Harrison, but has a larger second molar, a slightly larger sectorial and more closely crowded, obliquely placed anterior premolars.

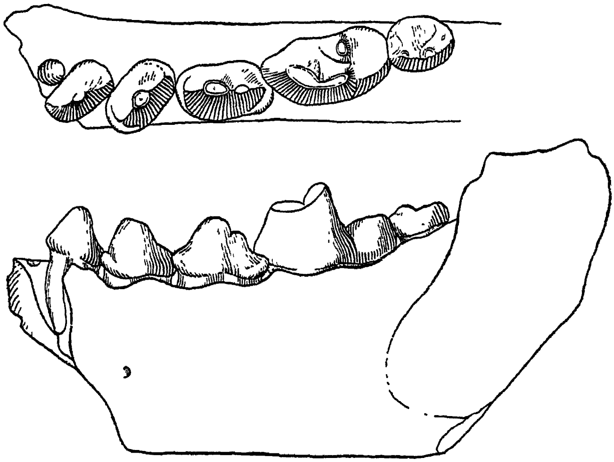


FIG. 3. *Brachypsalis obliquidens,* lower jaw, type specimen, external view, and crown view of the teeth, both natural size, No. 12070.

MEASUREMENTS.

Length, $p_{\overline{1}}$-$m_{\overline{2}}$	56
Length, $p_{\overline{1}}$-$p_{\overline{4}}$	32
Length, 1$m_{\overline{1}}$-$m_{\overline{2}}$	26
$p_{\overline{2}}$	9¾ × 6
p_3	11 × 7
$p_{\overline{4}}$	13 × 7¾
$m_{\overline{1}}$	17½ × 9
$m_{\overline{2}}$	9 × 7½

MARTES GLAREÆ sp. nov.

Type No. 12071 Princeton University Geological Museum, collecting locality 1000C, the left ramus of the lower jaw with $p_{\overline{3}}$, $_{\overline{4}}$ and $m_{\overline{1}}$ and alveoli of the canine, $p_{\overline{1}}$, $_{\overline{2}}$ and $m_{\overline{2}}$ (Fig. 4). In size, close to the type of *M. ogygia* Matthew from Horizon E of the Upper Miocene of Colorado, but differing in the presence of $p_{\overline{1}}$ (represented by a small alveolus), the slightly larger, more laterally compressed $p_{\overline{3}}$ which lacks a posterior accessory cusp as in *ogygia* and some existing species, the presence of this cusp on $p_{\overline{4}}$ (only slightly less developed than in specimens referred to *M. americana* with which comparison was made), and the larger heel on $m_{\overline{1}}$. In both *M. ogygia* and *M. glareæ* the metaconid or $m_{\overline{1}}$ is more sharply separated than in specimens referred to *M. americana* which I have

examined. *M. minor* Douglass from near the bottom of the Lower Madison Valley Loup Fork beds and *M. furlongi* Merriam from the Thousand Creek beds, Thousand Creek, Nevada, are smaller forms, while *M. parviloba* Cope from the Middle Miocene of Colorado is a larger animal than either *ogygia* or *glareæ,* and *M.* (*Putorius*) *nambianus* from the New Mexican Loup Fork has a shorter jaw than either of the species just mentioned. It is approached in size by specimens in the Princeton University osteological collection referred to *M. americana,* but differs, in addition to the characters cited above, in the larger heels and heavier anterior basal ledges on the premolars and the greater degree of lateral compression of these teeth.

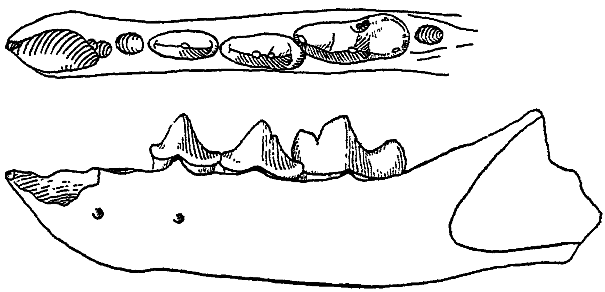


FIG. 4. *Martes glareæ,* lower jaw, type specimen, external view and crown view of the teeth, twice natural size, No. 12071.

MEASUREMENTS.

Length, $p_{\overline{3}}$-$m_{\overline{1}}$	17
$p_{\overline{3}}$	5 × 2
$p_{\overline{4}}$	5.8 × 2.1
$m_{\overline{1}}$	8 × 3

PSEUDAELURUS near INTREPIDUS Leidy.

The presence in the Snake Creek fauna of a cat not far removed from *Pseudaelurus intrepidus* Leidy is indicated by a jaw fragment No. 12081 Princeton University Geological Museum, collecting locality 1000C, which agrees with Leidy's type fairly closely in the dimensions of the jaw, but differs in having the teeth a little smaller and the posterior accessory cusps and heels on the premolars less strongly developed. A further difference, which may be of little importance, is found in the position of the mental foramina which,

in *P. intrepidus,* occur below the alveolus for $p_{\overline{2}}$ and the anterior root of $p_{\overline{3}}$ respectively, while in the Snake Creek form they lie below the posterior root of $p_{\overline{3}}$ and a little in front of its anterior root. The alveolus for $p_{\overline{2}}$ is quite small and must have supported a minute vestigial single-rooted tooth.

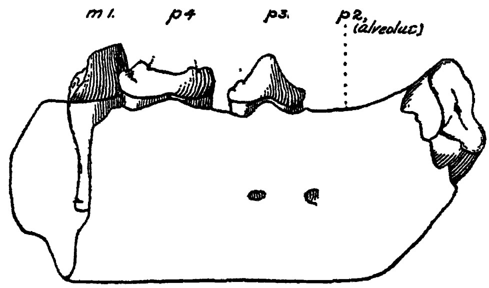


FIG. 5. *Pseudælurus* near *intrepidus,* lower jaw, right side, No. 12081, natural size.

FELID gen. et sp. indet.

A large non-machærodont cat is represented by a fragment of the left mandibular ramus No. 12073 Princeton University Geological Museum, collecting locality 1000A, in which are preserved the alveoli for three incisors, the base of a very large laterally flattened canine and alveoli for two premolars, a very small single-rooted $p_{\overline{2}}$ and a large double-rooted $p_{\overline{3}}$. The chin is not flanged but the symphysial region projects a short distance below the level of the lower border of the jaw.

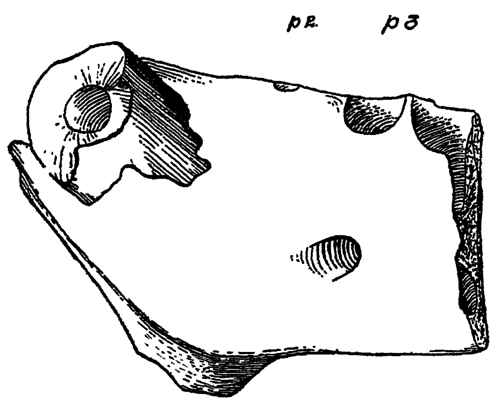


FIG. 6. Indeterminate felid, fragment of the lower jaw, left side, lateral view, No. 12073, natural size.

Edentate (?Megalonychid).

A single imperfect claw, "definitely recognizable as of Gravigrade relationship" and comparable "with some of the smaller Megalonychidæ" is reported by Matthew and Cook from the Snake Creek beds. Further confirmation of the presence of edentates is found in a navicular bone (Fig. 7) unquestionably of a Gravigrade, about two thirds the size of the navicular of *Megalonyx jeffersoni* and of much the same general type, obtained by the Princeton expedition at collecting locality 1000C.

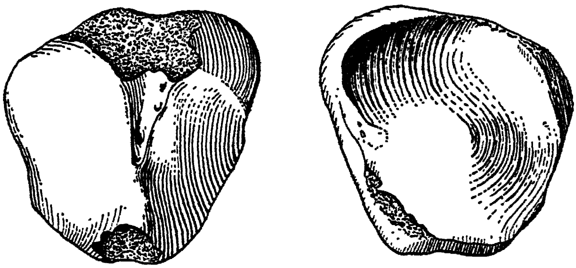


Fig. 7. Navicular bone of gravigrade edentate, upper and lower views, two thirds natural size, No. 12079.

Mastodons.

Mastodons of two types are indicated in the Princeton Snake Creek collection by several complete molars, most of which seem

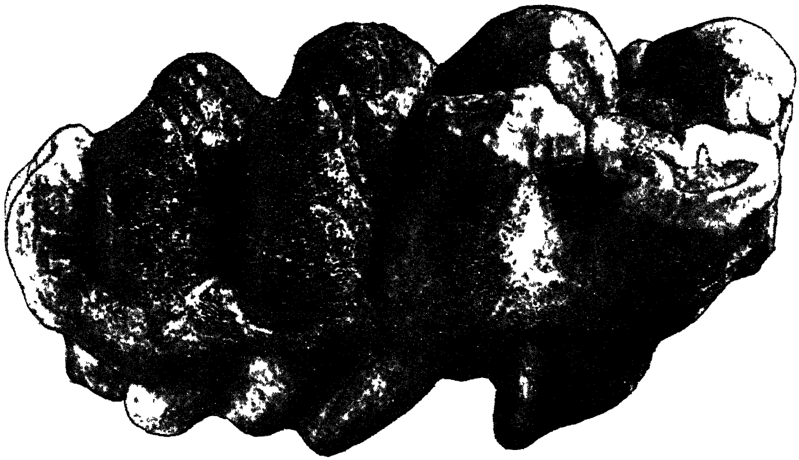


Fig. 8. *Gomphotherium* sp., right last lower molar, one half natural size. No. 12064 Princeton University Geological Museum, collecting locality 1000 A.

referable to *Gomphotherium,* with a last lower molar carrying four cross-crests and a heel and having the intervening valleys blocked by large accessory tubercles (Fig. 8). A smaller form (Fig. 9), also with four cross-crests and a heel in $m_{\overline{3}}$, has the summits of the crests much more acute than in the *Gomphotherium* type and the valleys as free from accessory tubercles as in the corresponding tooth of *Mastodon americanus* to which the Snake Creek form is, possibly, related. Accessory ridges occur on the front and rear of the external half of each crest, but are no more strongly developed than in *M. americanus.* The last lower molar of the latter does not decrease in width posteriorly as rapidly as does the tooth here considered, but in other respects they closely resemble each other. The crown is unworn and there is no trace of cement.

FIG. 9. *?Mastodon* sp., left last lower molar, two thirds natural size. No. 12116 Princeton University Geological Museum, collecting locality 1000 A.

INCERTÆ SEDIS.

A fragment of the left ramus of a lower jaw, No. 12091 Princeton University Geological Museum, collecting locality 1000A, has not been determined generically (Fig. 10). The specimen shows alveoli for two incisors and part of the root of a third. The first alveolus is very large and shallow and the second narrow and deep. The fragment of the root of the third incisor is strongly compressed

laterally and almost quadrangular in cross-section. These are followed after an intervening space, throughout which the dental margin of the ramus is broken, by a small, single-rooted, conical

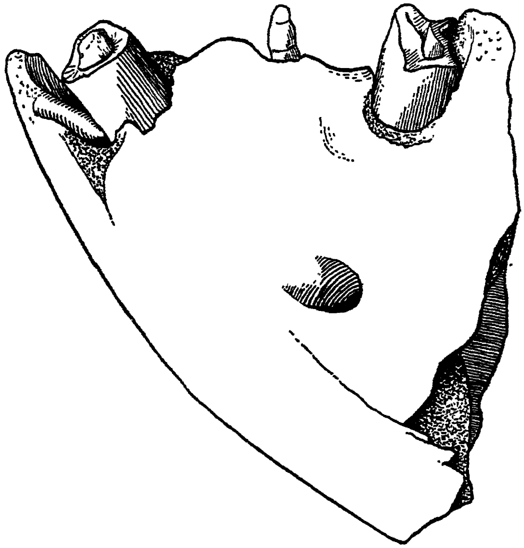


FIG. 10. *Genus incert. sed.* No. 12091, a fragment of the left ramus of the lower jaw, outer side, two thirds natural size.

tooth with enamel-covered crown. A second diastema, with undamaged margin, separates this tooth from the anterior root of a large, evidently deciduous tooth, beneath which, in the jaw, is the cavity for a still larger permanent tooth. The root of $i_{\overline{3}}$ seems to have projected into this cavity where it has been truncated by absorption. The symphysis is firmly fused, a small portion of the right ramus adhering to the left one and showing part of the alveolus for the first incisor of the right side.

MEASUREMENTS.

$i_{\overline{1}}$, anteroposterior diameter of alveolus (approximate)	23
$i_{\overline{1}}$, transverse diameter of alveolus (approximate)	18½
$i_{\overline{2}}$, anteroposterior diameter of alveolus (approximate)	6½
$i_{\overline{2}}$, transverse diameter of alveolus (approximate)	9
$i_{\overline{3}}$, anteroposterior diameter of root	16
$i_{\overline{3}}$, transverse diameter of root	9
?c, anteroposterior and transverse diameters	6

Length of diastema ?c-dp	15
Depth of jaw below middle of dp	107
Thickness of jaw at level of mental foramen	45

ARCHÆOHIPPUS sp.

A small short-crowned $p_{\overline{2}}$ of the right side (No. 12128 Princeton University Geological Museum, colecting locality 1000B) agrees in structure with the upper teeth of *Archæohippus* in the complete union of the metaloph and ectoloph, the distinct protoconule, and open prefossette, there being no anterior median enamel fold on the wall of the metaloph. This horse has not been reported hitherto from any horizon above the Middle Miocene Mascall beds of Oregon.

MEASUREMENTS.

Greatest anteroposterior diameter	13
Greatest transverse diameter	13

PRONOMOTHERIUM SIOUENSE sp. nov.

Type No. 12057 Princeton University Geological Museum, collecting locality 1000C, the right ramus of the lower jaw with $p_{\overline{1}}$-$m_{\overline{3}}$ and alveoli of $i_{\overline{1}}$–c. Tooth crowns worn. A smaller form than

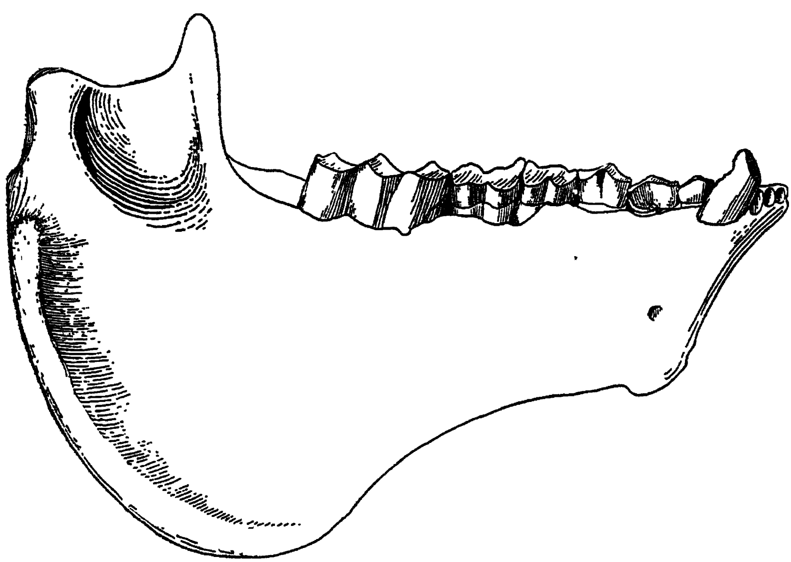


FIG. 11. *Pronomotherium siouense*, lower jaw, type specimen, external view, $\times 1\frac{1}{2}$.

either of the better known Miocene species (*P. laticeps* and *P. altiramis*) from which it can be separated by differences both in size and proportions.

MEASUREMENTS.

Length of jaw	208
Depth beneath p_3	57
Depth beneath m_1	53
Depth beneath back part of m_2	55
Depth beneath last lobe of m_3	94
Depth coronoid to angle	147
Length lower dental series	132+
Length lower premolar-molar series	125
Length lower premolar series	50
Length lower molar series	75

PROTOLABIS PRINCETONIANUS sp. nov.

Type No. 12053 Princeton University Geological Museum, collecting locality 1000C, an uncrushed skull, sand-worn on the right side which lay uppermost, associated with most of the left ramus of the lower jaw, a fragment of the right ramus and an ulna-radius. The limb bone belongs to a camel but may not pertain to the same individual as the skull. In size, there is close agreement with *Protolabis longiceps* Matthew from the Colorado Loup Fork (Pawnee Creek beds), but a comparison of the two skulls brings out certain minor differences which appear to be of specific value. In *P. princetonianus,* the anterior facial vacuity is far larger than in the Colorado form, with the premaxillæ extending above it and reaching farther back than in that species. Another marked difference appears in the absence of an abrupt constriction of the face in front of $p^{\underline{2}}$ which produces the sudden incurving of the tooth row seen in *longiceps* in contrast with the gradual taper of this region in the Princeton specimen. Various differences in dental structures are also noticeable, as follows: $p^{\underline{2}}$ thicker and heavier and $p^{\underline{3}}$ less reduced and with posteroexternal groove deeper than in *P. longiceps;* $p^{\underline{4}}$, if anything, larger in *longiceps* than in *princetonianus.* Lower premolars somewhat less reduced and molar crowns somewhat higher, and posteroexternal groove in $p_{\overline{4}}$ placed nearer hinder end of tooth than in *longiceps;* $p_{\overline{3}}$ with distinct anterior cusp which is absent in the last named form.

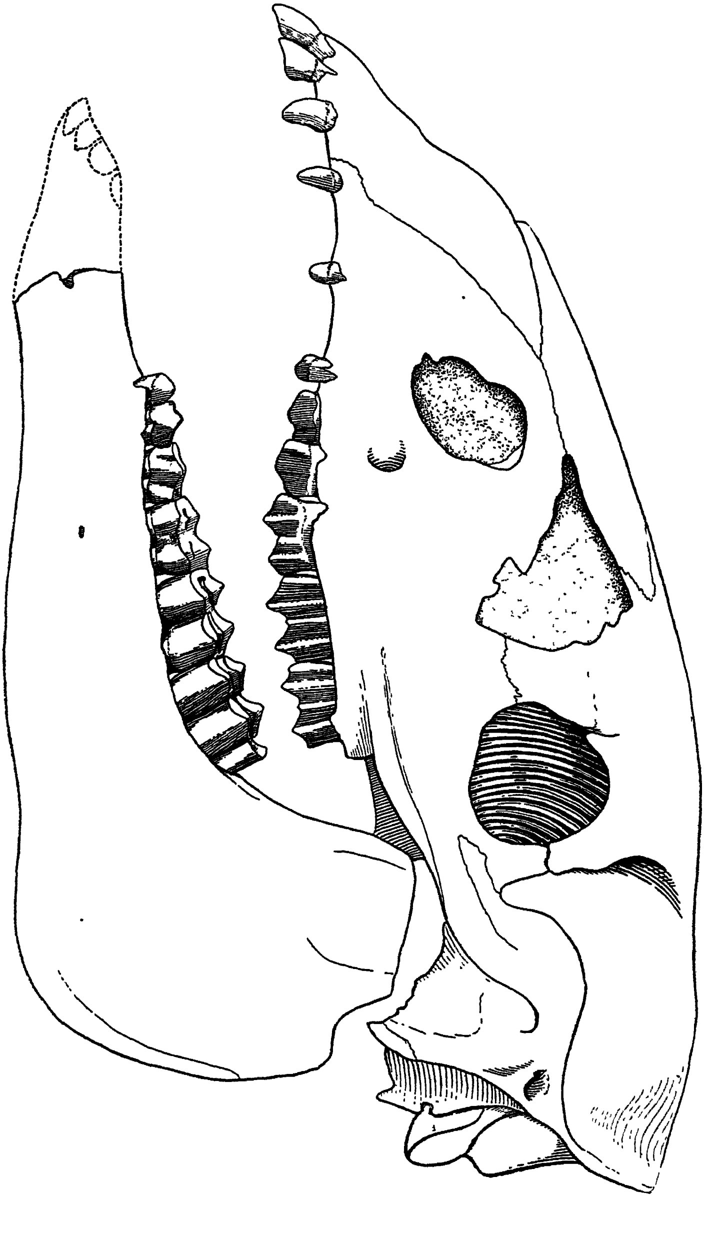


FIG. 12. *Protolabis princetonianus*, type specimen, left side of skull and lower jaw, one half natural size, No 12053. Symphysis of lower jaw restored in outline from another specimen of the same species.

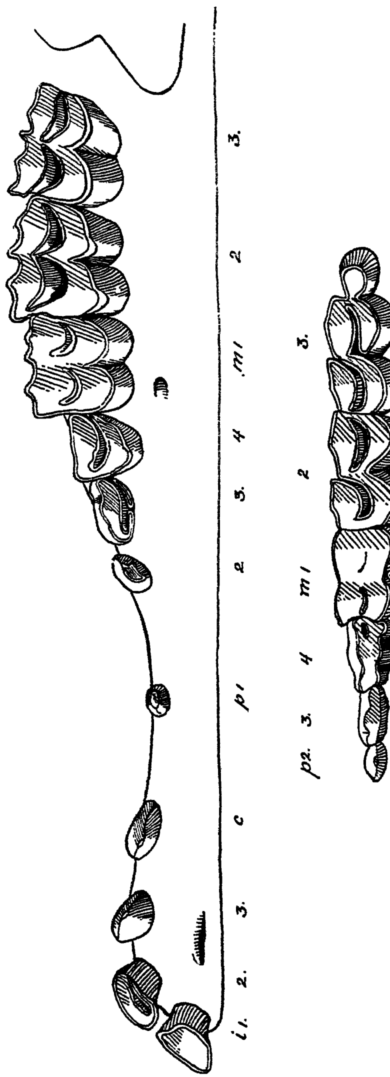


FIG. 13. *Protolabis princetonianus*, type specimen, crown view of the upper and lower teeth, two thirds natural size, No. 12053.

MEASUREMENTS.

Total length of skull (incisors to condyles)	310
Length, i^1-m^3	right 195, left 199
Length, p^1-m^3	right 121, left 127
Length, premolar series	right 59½, left 64
Length, diastema behind i_3	right 11, left 9
Length, diastema behind c	18
Length, diastema behind p^1	right 18, left 20
Length, lower premolar-molar series	106
Length, lower premolars	33
Depth of jaw in front of $p_{\overline{2}}$	32
Depth of jaw below middle of $m_{\overline{3}}$	40
Length of radius	195
Width of radial shaft at middle	24

DREPANOMERYX FALCIFORMIS gen. et sp. nov.

Type No. 12072 Princeton University Geological Museum, collecting locality 1000C, a horn of the left side (lacking tip) and the basal portion of the right horn (Figs. 14, 15).

Frontal not cavernous at base of horns. Horns non-deciduous, rising immediately above upper posterior margin of orbit, sloping backward and upward and at the same time curving inward, at base almost circular, but flattening upward in the transverse plane extending backward and inward from the orbits, producing a scimitar-like structure which curves inward toward its fellow on the opposite side. Horns without any suggestion of twist, proximal half comparatively smooth and free from pits and irregularities, such faint groovings as are present being longitudinal. Distally, and especially toward the outer margin, the surface is rough and pitted, but this seems to be due to sand-blasting or water-wear which has destroyed the outer table of bone. A broad groove is visible throughout the central portion of the shaft on the posterior aspect of the horn. Horns solid throughout, the surface, texture resembling that of the Pronghorn Antelope.

No teeth have been found in the Snake Creek beds which can be referred, even provisionally, to the new form, unless those which have been correlated by Matthew and Cook with their *Neotragocerus improvisus,* and the lower jaw described under that genus in the present paper, should be associated with the curved type of horn found in *Drepanomeryx* rather than with the straight horns of *Neotragocerus.*

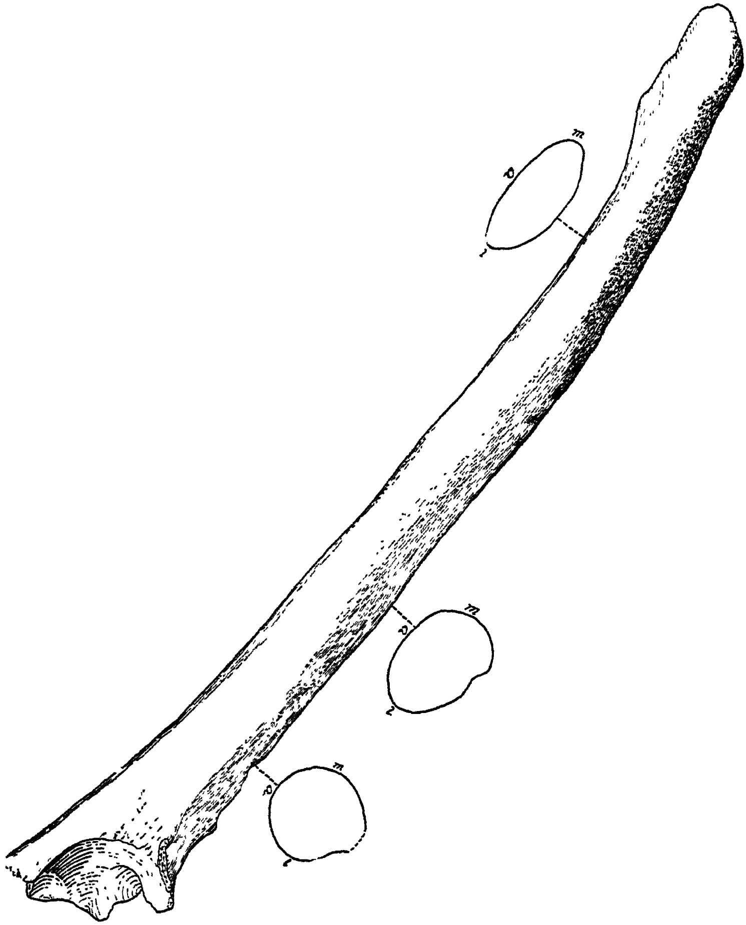


FIG. 14. *Drepanomeryx falciformis,* type specimen, lateral aspect of the left horn, one half natural size, No. 12072. *l, m, a* in cross-sections = lateral, median and anterior margins.

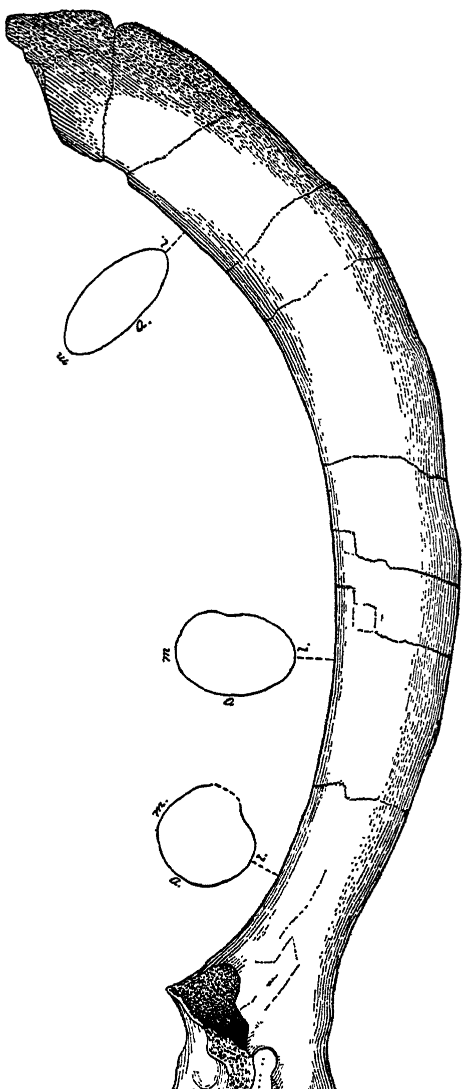


Fig. 15. *Drepanomeryx falciformis*, type specimen, anterior aspect of the left horn, one half natural size, No. 12072. *l*, *m*, *a* in cross-sections = lateral, median and anterior margins; *s*, supraorbital foramen.

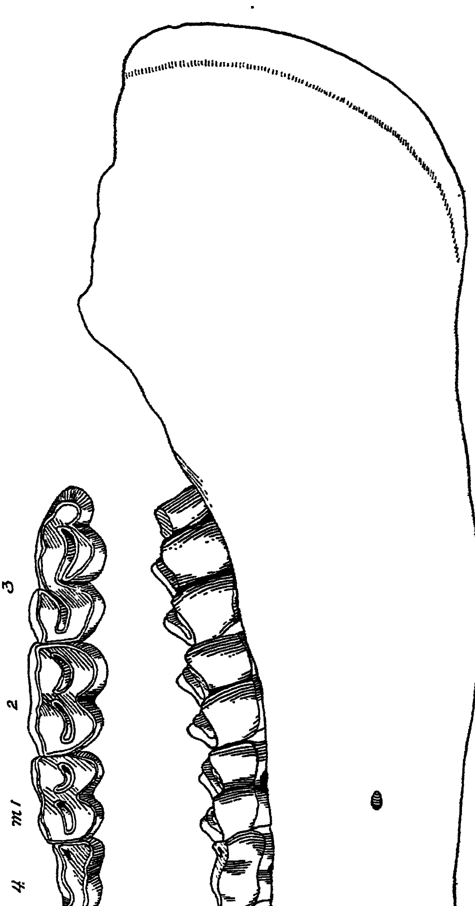


Fig. 16. *?Neotragocerus improvisus*, left ramus of the lower jaw, side view, and crown view of the teeth, two thirds natural size, No. 12106.

NEOTRAGOCERUS IMPROVISUS Matthew and Cook.

The left ramus of a lower jaw (No. 12106 Princeton University Geological Museum, collecting locality 1000C), which is doubtfully referred to this form, supports brachyodont molars which register almost exactly with the upper teeth selected by Matthew and Cook as paratypes of *Neotragocerus improvisus.* With the discovery in the Snake Creek beds of scimitar-shaped horns (*Drepanomeryx* gen. nov.), presumably of antelope-like animals, correlation of the straight *Neotragocerus* type of horn with jaw fragments, both upper and lower, supporting short-crowned teeth becomes even more provisional than it has hitherto been, since either type of horn is large enough to fit an animal of the size of those to which the jaws belonged.

DROMOMERYX WHITFORDI sp. nov.

Type No. 12054 Princeton University Geological Museum, collecting locality 1000C, an associated pair of horn bases (Fig. 17). Paratype No. 12086 Princeton University Geological Museum, the right ramus of a lower jaw, unassociated with the horns but from the same collecting locality (Fig. 18). The species is named in honor of my assistant in the field, Mr. A. C. Whitford. Horn bases about one third wider than in *D. borealis,* with the posterior upper corner of the wing-like expansion at the base of the horn

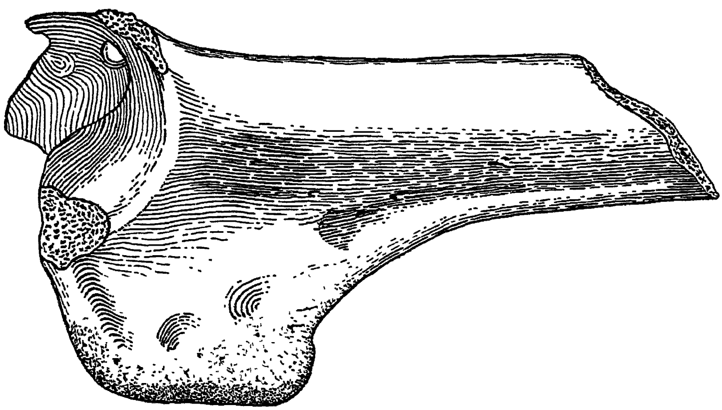


FIG. 17. *Dromomeryx whitfordi,* type specimen, base of left horn, outer side, two thirds natural size. One of an associated pair, No. 12054.

sharply angular instead of a flowing curve as in *D. borealis*. Lower jaw of practically the same size as in that species and dentition not specifically separable therefrom.

The inclusion in the same new species of type material not found associated is most unsafe. In this instance it seems justifiable because the collections made by two parties (American Museum and Princeton) have shown the presence of but one species of *Dromomeryx* in the Snake Creek beds, the so-called *Palæomeryx* of Matthew and Cook being undoubtedly *Dromomeryx* and not separable from the new species here described.

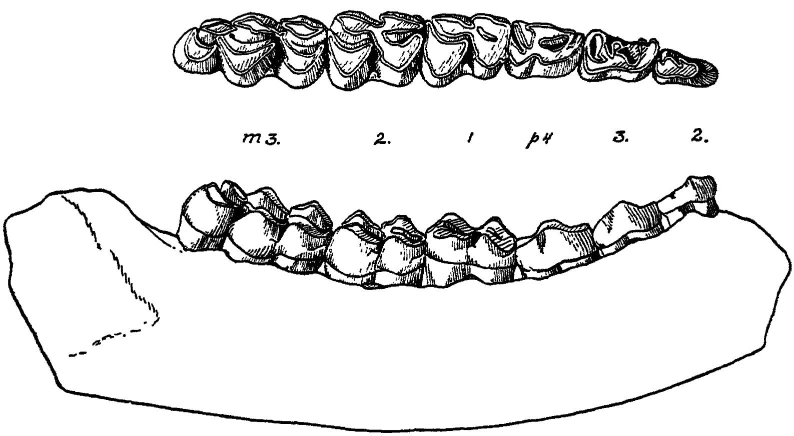


FIG. 18. *Dromomeryx whitfordi,* paratype, right ramus of the lower jaw, side view, and crown view of the teeth, two thirds natural size, No. 12086. The distance from p_2-m_3 is a little greater in the crown view, owing to elimination in the drawing of the fore-shortening due to curvature of dental series.

MEASUREMENTS.

Width of horn-base across middle of wing-like process	73
Anteroposterior diameter of beam three inches above base ...	30
Transverse diameter of beam three inches above base	25
Legnth, p_2-m_3 measured as chord of arc	109
Length, m_1-m_3	67½
p_2, anteroposterior 12⅓, transverse	6⅔
p_3, anteroposterior 14½, transverse	10
p_4, anteroposterior 15, transverse	10½
m_1' anteroposterior 17, transverse	14
m_2' anteroposterior 19½, transverse	15
m_3, anteroposterior 31, transverse	15
Depth of jaw beneath p_2	31
Depth of jaw beneath m_3	31½

PRINCETON UNIVERSITY, April, 1915.

EXPLORATIONS OVER THE VIBRATING SURFACES OF TELEPHONIC DIAPHRAGMS UNDER SIMPLE IMPRESSED TONES.

By A. E. KENNELLY and H. O. TAYLOR.

(*Read April 22, 1915.*)

The following research was carried on, at the Massachusetts Institute of Technology, under an appropriation from the American Telephone & Telegraph Co. during the year 1914–1915. The experimental work was carried out at Pierce Hall, Harvard University.

The object of the investigation was to explore the amplitude of the small harmonic vibrations of a circular diaphragm of telephonic type, clamped around the edge, and to compare the observed values with those which had been already deduced mathematically. Hitherto, so far as we are aware, the amplitude of vibration of a telephone diaphragm has been determined only at one point on the surface, usually the center,[1] The observations here reported differ from those heretofore obtained, in extending over the entire surface of the diaphragms.

Exploring Apparatus.

The exploring device, or "explorer," devised and constructed for this research, consists of a tiny triangular mirror fastened to a little phosphor-bronze stirrup strip, and having its point applied, by means of torsion in the strip, to the surface of the vibrating diaphragm at the point to be explored. The natural frequency of the mirror being much greater than that impressed on the diaphragm, the mirror is able to follow the vibrations of the latter, without breaking out of contact. The pressure exerted by the mirror on the diaphragm is so small as not materially to affect the diaphragm's vibration. A beam of light, reflected from the mirror on to a translucent scale, was thus set into vibrations synchronous with, and

[1] See Appended Bibliography, Nos. 2, 4, 7, 9 and 10.

proportional to, the vibrations of the diaphragm at the point of contact.

The vibration explorer is shown in side elevation at Fig. 1, in top view at Fig. 2, and in section, through center of the diaphragm, in Fig. 3. A fairly massive rectangular brass frame holds a plate sliding in grooves. The crank at the bottom of Fig. 1 controls this

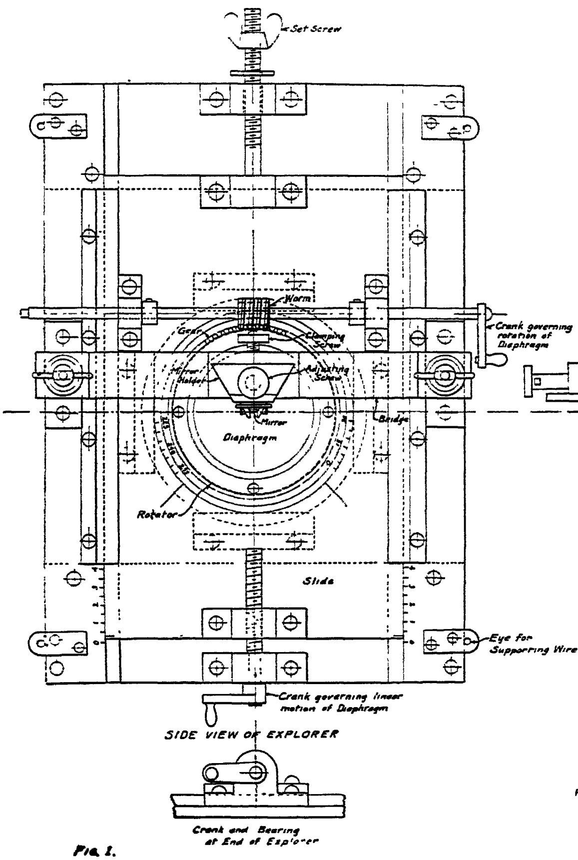


FIG. 1.

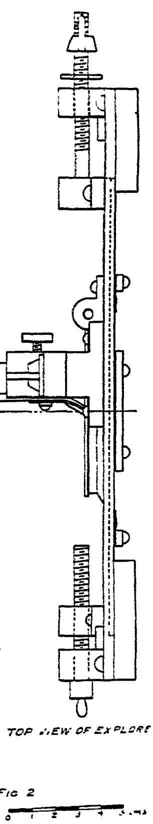


FIG. 2.

sliding motion, with the aid of the set screw at the other end. At the center of the sliding plate is a circular frame, into which is clamped the diaphragm to be tested. The circular frame can be rotated in its own plane by means of the crank at the right hand of Fig. 1.

A stout brass bridge is fastened to the sides of the rectangular frame. At the center of this bridge is the mirror-holder shown in detail at Fig. 3. The mirror-holder slides in a groove provided in the bridge, and is clamped therein by a clamping screw *S*. A fine-motion screw *M* is also provided, for adjusting the position of the mirror. One turn of *M* advances the mirror 0.8 mm. (1/32 inch). By means of an auxiliary mirror fastened beneath the top of the screw *M*, the angle through which the screw is advanced may be

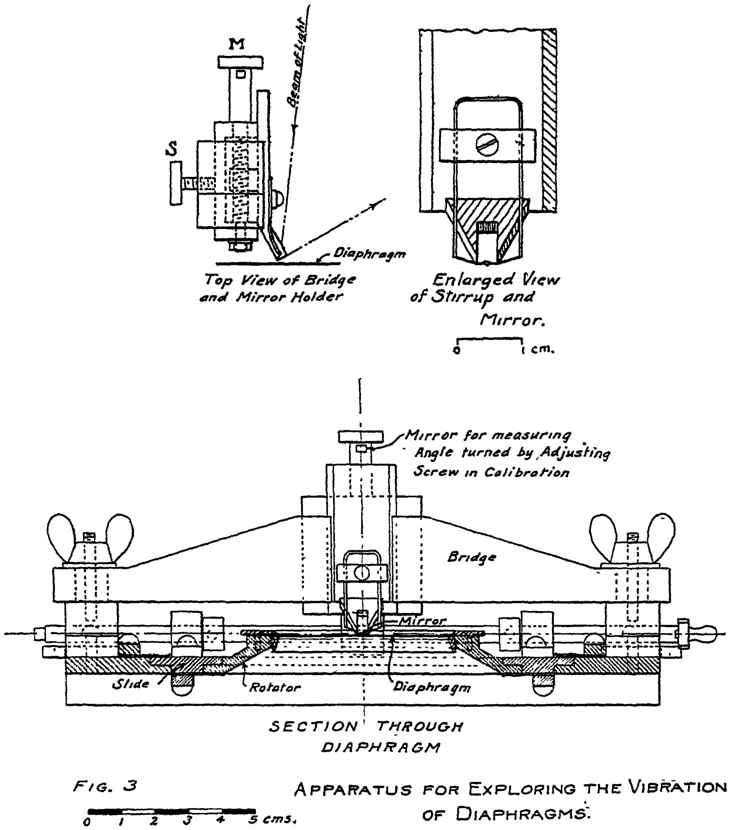


FIG. 3 APPARATUS FOR EXPLORING THE VIBRATION OF DIAPHRAGMS.

measured, for calibrating the indications of the instrument. Adjustment can be made to 1 deg. of rotation, or 2.2 μ; i. e. $\left(\frac{0.8}{360}\text{ mm.}\right)$ assuming that backlash is guarded against.

The construction of the apparatus is such, that the mirror is held at all times at the center of the brass rectangular frame; while by means of the two crank adjustments, the diaphragm to be explored can be moved so as to bring any part of its surface beneath the mirror. With the aid of the scales of distance and angle shown in Fig. 1, the position of the mirror with respect to the diaphragm can be adjusted and read off to polar coördinates (r, θ). The motion in r is controlled by the crank at the bottom, to 0.1 mm.; while the angular motion in θ is controlled by the crank at the side, to 1°, or less if desired. The slide is held in position by flat springs, attached to the rectangular frame, so as to keep the motion of the slide confined to its own plane. A similar construction is used with the circular frame. It is important that the plane of the diaphragm shall not be disturbed when either crank is operated. The weight of the whole explorer is 4.63 kgs. (10.2 lbs).

A magnified view of the mirror, and its stirrup frame, is shown at the top of Fig. 3. The mirror, of silvered glass, about 0.1 mm. thick, is cut in the shape of an equilateral triangle, about 1 mm. in length of side. One vertex of the mirror is applied to the surface of the diaphragm, and the mirror is fastened with sealing wax across a thin phosphor-bronze strip. This strip is approximately 3 mm. long between abutments, 0.02 mm. wide, and 0.013 mm. thick. The weight of the mirror is about 1 milligram, without varnish or sealing wax. Its natural frequency of vibration, as obtained photographically, is about 2,500 ~. These little mirrors are apt to break off the stirrup strip; so that they have to be renewed and recalibrated occasionally. The pressure exerted on the diaphragm by the point of the mirror, as measured by an auxiliary test, is approximately 200 dynes (204 mgm. wt.). A pressure of this order seems to be desirable, so as to obtain a natural frequency of 2,500 ~. If, however, explorations are confined to lower diaphragm frequencies, the natural frequency of the explorer mirror, and its pressure on the diaphragm, may be reduced accordingly.

The diaphragm to be explored is 5.4 cm. in diameter, and is placed in the circular frame. It is clamped tightly into this frame, with the ring clamp shown in Fig. 3, which had a radius of 2.62 cm. when no auxiliary clamping rings were used. The vibration explorer

is then suspended on wires from the ceiling, or other convenient support, in order to suppress building vibrations of high frequency; so as to support the explored diaphragm in a vertical plane. The mirror-holder is then advanced towards the diaphragm, and clamped by screw *S*. The mirror is now carefully brought into contact with the surface of the diaphragm by adjusting screw *M*. A picture of the explorer is presented in Fig. 4. The suspension wires *ww*,

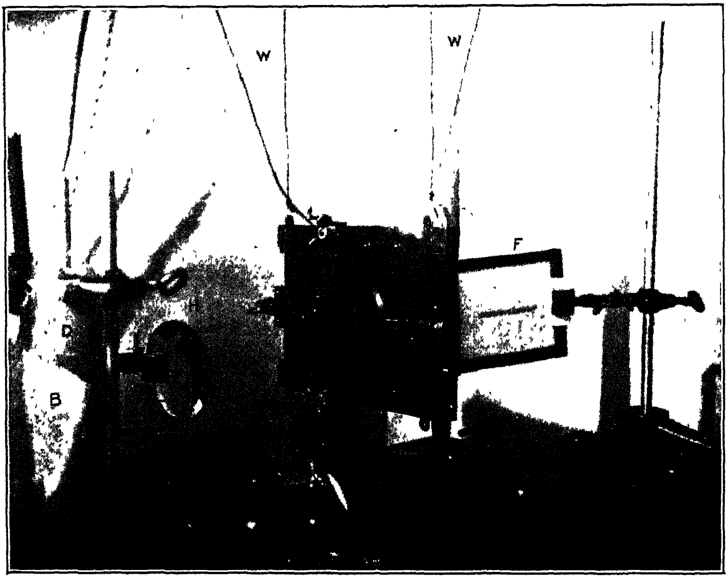


FIG. 4. Vibration Explorer in Booth.

support the instrument. The condensing and focusing lens *H* throws a narrow arc-light beam upon the exploring mirror, which reflects it on to the translucent graduated screen *F*. With the diaphragm at rest, the spot on this screen is a narrow, sharp, vertical, luminous strip. When the diaphragm is set in vibration, the mirror in contact with it vibrates synchronously, and the spot is spread into a luminous band, the limits of which are easily read on the graduated translucent scale. If the motions of diaphragm and mirror are simple harmonic motions, the luminous band shows no discontinuities of intensity. If, however, there is a complex harmonic motion in the diaphragm, the luminous band will show bright and dark

patches, either quiescent, or with beats. By means of the optical magnification of amplitude that can be effected with such an exploring mirror and scale, diaphragm vibrations of amplitude 0.1 μ (*i. e.*, 10^{-5} cm.), or less, can be observed; although the precision of measurement falls off considerably, for a diaphragm amplitude below 0.5 μ (half a micron).

Optical System.

The optical system employed with the vibration explorer is diagrammatically indicated in Fig. 5. The stereopticon arc-lamp A throws a powerful condensed beam of light on the pinhole B, in a brass vertical screen. A set of small powerful collimating lenses C

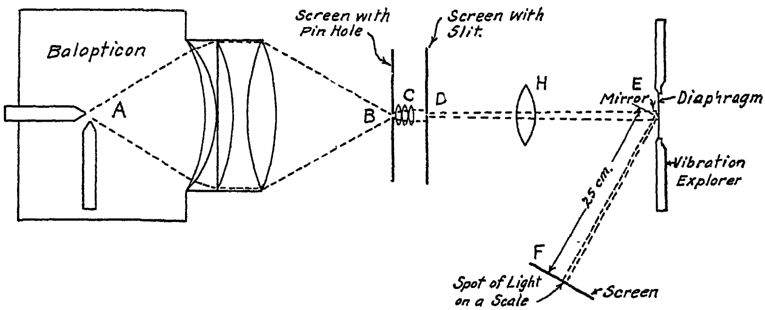


Fig. 5. Diagram of Optical System used with Vibration Explorer.

throws the nearly paralleled beam through the screen and slit D, as well as the focussing lens H, on the exploring mirror E, whence it is reflected to the translucent screen F, at a convenient distance, in this case 25 cm. An image of the slit in screen D is then sharply focused at F. In Fig. 6, it is indicated geometrically that the amplitude e of the diaphragm's displacement is equal to the continued product of the observed amplitude d of the luminous band, the ratio of l (the radius arm of the mirror), to $2L$ the double distance of the mirror from the screen, and the cosine of the angle ϕ between the radius arm of the mirror and the plane of the diaphragm. In order to avoid frequent changes in ϕ, it is desirable to keep constant the zero of the spot at the center of the graduated scale F, and with it the contacting angle of the mirror. The numerical

expression $M = 2L/l \cos\phi$ may be called the *magnification-factor* of the explorer. As ordinarily employed, $2L = 50$ cm., $l = 0.05$ cm., $\phi = 45°$ approximately, or $\cos\phi = 0.7$; so that $M = 1{,}400$ approximately, varying in different sets of measurements between

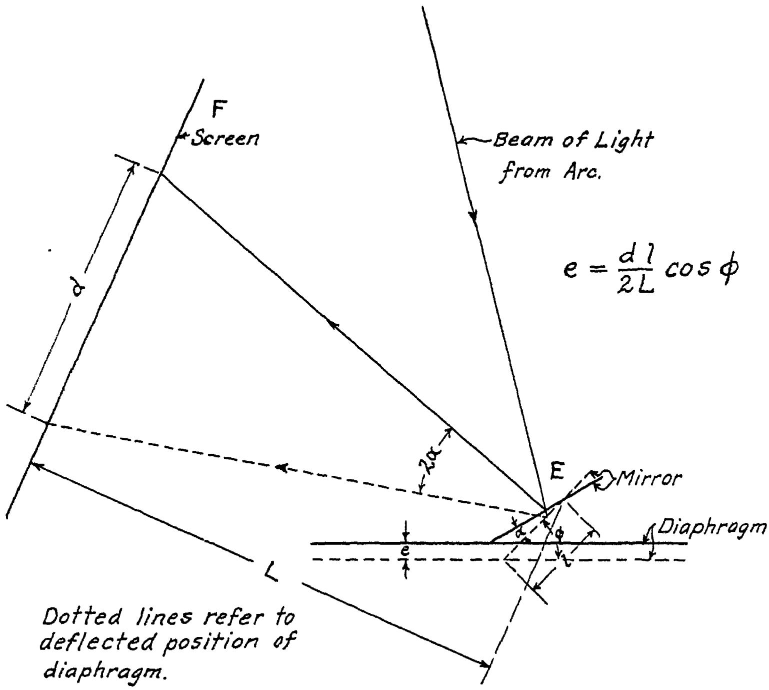


FIG. 6. Diagram Showing Action between Mirror and Diaphragm in Explorer.

800 and 1,500. Had it been necessary, this magnification-factor might have been considerably increased, by increasing the distance L between mirror and scale; although the reduction in luminous-spot intensity, at increasing ranges, prevents the precision of the observations from increasing in the same proportion as the magnification-factor. At $L = 25$ cm., the amplitude of luminous band could be read to 0.1 mm. on the graduated translucent scale F.

SOURCE OF DIAPHRAGM VIBRATIONS.

Two sources of vibrations were used in different series of tests, (1) acoustic, (2) electromagnetic.

(1) The acoustic vibrations were supplied from one of a series of small organ-pipes, giving fairly simple musical tones between C_2 of 128 ~, and C_6 of 2,048 ~. The organ-pipe selected was mounted vertically in a block on the table, at the back of the vibration explorer, and supplied with air at constant pressure (about 18 cm. of water) from a pneumatic tank. The whole apparatus was placed inside a sound-damping wooden-frame booth (274 cm. × 183 cm. × 214 cm. high), lined on the inside with hair-felt, 2.5 cm. thick, surfaced with thin cloth. The observer, after turning on the air to the organ-pipe, observed the amplitude of the luminous band on the translucent screen *F*, Figs. 4 to 6, as the mirror was applied to different successive points on the diaphragm.

(2) The clamping ring of the diaphragm in the explorer was chosen of such dimensions that a standard telephone receiver could be substituted for it. In this case, a steel diaphragm had to be employed. The telephone was then operated by a feeble measured alternating current (2.0 milliamperes) obtained from a Vreeland mercury-arc oscillator having a frequency adjustable, by successive steps, between 430 ~ and 2,500 ~.[2]

Exploration with Diaphragm No. 1.

Diaphragm No. 1 was a telephone-receiver diaphragm of steel, japanned on one side. Its dimensions are given in Table III. The diaphragm was clamped, around the boundary, between opposing circular knife-edges.

TABLE I.

Vibration Amplitudes over Diaphragm No. 1, at Frequency 608 ~, for Nine Different Azimuths θ, and Seven Different Radial Distances r.

Radial Distance, r Cm.	Vibration Amplitude Observed with Explorer (Microns) at Different Azimuths θ.								
	0° μ	40° μ	80° μ	120° μ	160° μ	200° μ	240° μ	280° μ	320° μ
−0.08	13.8	12.1	11.7	14.0	13.4	10.4	10.8	13.3	12.0
+0.31	12.7	10.9	11.3	12.3	12.7	9.7	10.6	12.6	11.6
+0.69	9.7	8.0	8.9	10.4	10.4	8.1	8.8	11.5	9.5
+1.06	6.6	5.9	6.4	6.8	7.0	6.2	6.4	7.1	6.8
+1.44	4.2	3.6	4.2	4.7	4.5	4.1	4.2	4.9	4.3
+1.82	2.5	2.2	2.1	2.5	2.5	2.3	2.4	2.5	2.4
+2.20	0.9	0.8	0.9	0.9	0.9	0.7	0.7	0.9	0.8
+2.54	0	0	0	0	0	0	0	0	0

[2] See Bibliography No. 5.

An organ-pipe of $D_4^\sharp$ (608 ~) was set up with its lip 5 cm. from the back of the diaphragm. An exploration was then made over the surface, at points differing by 40° in azimuth θ, and at successive increases in radius of about 3.3 mm. (7 steps in r, and 9 steps in θ, or 63 observations in all.) The preceding table gives the observed amplitudes of vibration deduced from the scale-deflections, with a magnification factor of $M = 1{,}180$.

It will be seen from the above table, that at any particular radius r, measured from the center of the diaphragm, the amplitudes at varying azimuths θ are substantially equal. The irregularities are small, but nevertheless seem larger than can be accounted for by errors in observations and are, perhaps, due to irregularities in the diaphragm. Fig. 7 shows the contour lines of vibration-amplitude in microns, the maximum amplitude being at or near the center, and amounting to 14μ. Such vibration amplitudes are larger than were usually obtained, and were specially reinforced in this case, in order to secure large deflections. It will be seen from the contour diagram, that the diaphragm was vibrating with its fundamental or gravest mode of motion; *i. e.*, a motion to-and-fro as a whole, without either nodal diameters or nodal circles. It is known that a circular diaphragm, clamped at the edge, is capable of vibrating in an indefinitely large number of ways, according to the

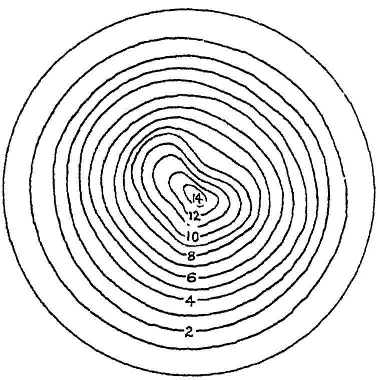


FIG. 7.

VIBRATION AMPLITUDE IN MICRONS. 608~ DIAPHRAGM No. 1.

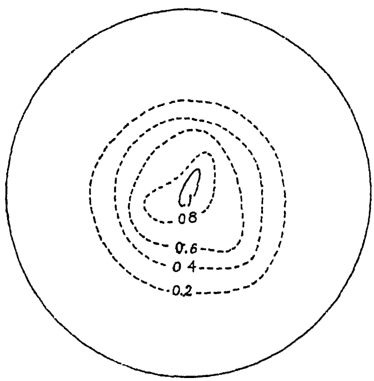


FIG. 8.

VIBRATION AMPLITUDE IN MICRONS. 2100~ DIAPHRAGM No. 1.

number of nodal circles, and also according to the number of nodal diameters present.[3]

A similar exploration was made over the diaphragm, with acoustic excitation from an organ-pipe giving C_6 (2,100 ~). Here the points of observation were in steps of about 3.3 mm. in r, and in steps of 40° in θ, as before, with magnification-factor, $M = 1,265$.

TABLE II.

VIBRATION AMPLITUDES OVER DIAPHRAGM NO. 1, AT FREQUENCY 2,100 ~, FOR NINE DIFFERENT AZIMUTHS θ, AND SEVEN DIFFERENT RADIAL DISTANCES r, FIVE ONLY GIVING READABLE DEFLECTIONS.

Radial Distance, r cm.	Vibration Amplitude Observed, with Explorer, at Different Azimuths θ.								
	0° μ	40° μ	80° μ	120° μ	160° μ	200° μ	240° μ	280° μ	320° μ
−0.08	0.70	0.95	0.95	0.95	0.87	1.02	0.95	0.87	0.95
+0.31	0.70	0.87	0.87	0.78	0.78	1.02	0.87	0.78	0.87
+0.69	0.62	0.78	0.78	0.62	0.62	0.78	0.62	0.62	0.78
+1.06	0.31	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.62
+1.44	0.16	0.16	0.16	0.08	0.08	0.08	0.08	0.08	0.23
+1.82	—	—	—	—	—	—	—	—	—
+2.20	—	—	—	—	—	—	—	—	—
+2.54	0	0	0	0	0	0	0	0	0

The vibration contour-lines for this case are given in Fig. 8. Here again it is seen that, setting aside irregularities in the diaphragm, and allowing for errors of observation (which are more noticeable with the small amplitudes of higher pitch), the mode of vibration is essentially fundamental, since there are no perceptible nodal circles or nodal diameters.

Having thus ascertained that both at pitch $D_4^\sharp$ (608 ~), and at C_6 (2,048 ~), the first mode of vibration was presented, a series of careful explorations were made at a number of intermediate pitches. These likewise all showed the first or fundamental mode of vibration. See Table II*A*.

Observations were also made, at organ-pipe frequencies down to 128 ~. Explorations would be very difficult to obtain on this diaphragm at such low frequencies, owing to the small vibration amplitudes produced; but the indications were that the fundamental mode of vibration was maintained throughout.

[3] See Appendix 1.

The conclusion, therefore, seems warranted that, for this particular steel telephone diaphragm, acoustically excited to frequencies as high as 2,100 ~, the fundamental mode of vibration is the only one that is maintained. If any higher modes of motion were present, they were too faint to be discerned. This does not mean that higher modes of motion could not be produced by any kind of excitation within the above ranges of frequency. The effects of very powerful vibrations were not investigated.

Since the natural frequency of this diaphragm, with flat clamping, was observed to be $n_0 = 824$ ~, and since, according to Bessel-Function theory, the natural frequency of the second mode of motion should be $2.09 n_0$, we should naturally expect to find this second mode of motion appearing at and above 1,720 ~. Its non-appearance may have been due to the uniformity of acoustic impressed force over the surface, which would tend to favor the first rather than the second mode of forced vibration.

The vibration-amplitude of the diaphragm was found to vary widely with the pitch of the exciting source. At or near the natural

TABLE II*A*.

Showing Fundamental Mode of Vibration Maintained for a Range of of Frequencies from 400 ~ to 1,800 ~.

Amplitudes of Vibration in Microns (μ) along Radius of Diaphragm No. 1, Flat-Clamped. $n_0 = 704$ ~.

Radial Distance, r Cm.	Frequency of Vibration.						
	400 ~ μ	500 ~ μ	750 ~ μ	1,000 ~ μ	1,250 ~ μ	1,500 ~ μ	1,800 ~ μ
.04	.8	1.6	7.8	1.3	1.3	.9	.3
.29	.8	1.6	7.7	1.3	1.2	.9	.3
.54	.7	1.5	7.2	1.1	1.1	.8	.3
.79	.6	1.4	6.3	.9	.9	.6	.2
1.04	.5	1.3	5.3	.8	.8	.5	.2
1.29	.4	1.0	3.8	.5	.6	.3	.1
1.55	.2	.7	3.0	.3	.4	.2	+
1.79	.1	.4	1.9	.2	.2	.1	+
2.04	+	.3	1.2	.1	.1	+	—
2.30	—	.1	.8	—	+	—	—
2.65	0	0	0	0	0	0	0

fundamental frequency of the diaphragm, the amplitude of the vibratory response was a maximum. Either above or below this

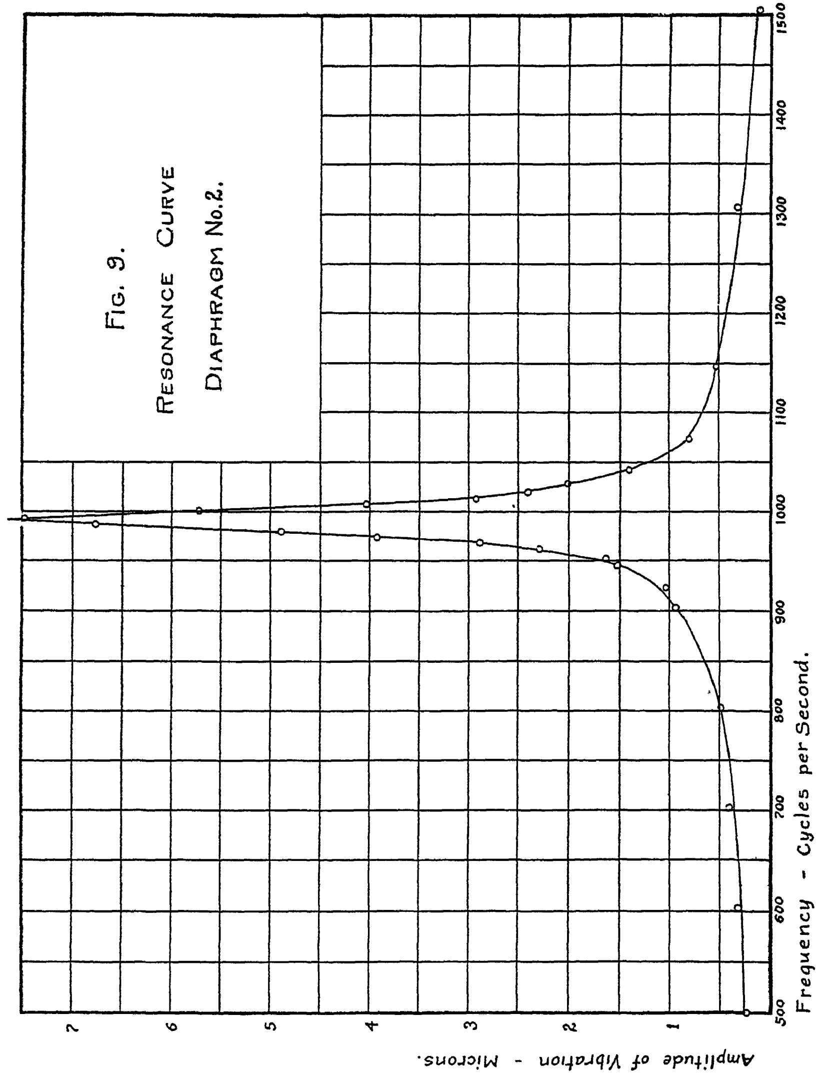


Fig. 9.
Resonance Curve
Diaphragm No. 2.

resonant frequency, the amplitude of vibration, shown by the explorer, fell off very markedly. The curve of relative amplitude at different frequencies is indicated in Fig. 9. It will be seen that when exciting the diaphragm with vibrations remote from the resonant frequency in either direction, the amplitude becomes so small that the degree of precision which may be obtainable near resonance is impossible to secure. The outline theory for this resonance curve, Fig. 9, is given in Appendix II. It is shown that if we multiply the successive ordinates by $\omega = 2\pi n$, the resulting velocity-values correspond to vector chords on a certain velocity circle.

Fig. 1*B* of Appendix I. gives the graph of the explored vibration amplitudes, at successive radial distances from the center of diaphragm No. 1, for the frequency 896 ~. It will be seen that the amplitude falls off smoothly from a maximum at or near the center ($r = 0$), to zero at the flat-clamped edge ($r = 2.62$). The application of Rayleigh's theory of free vibration to these curves is given in Appendix I. In general, the agreement between the acoustically forced amplitudes and theoretically computed free amplitudes was satisfactory.

At or near the resonant frequency, or natural frequency of a diaphragm, especially when its damping coefficient is small, so that the resonance is sharp, a small change either in impressed frequency, or in the constants of the diaphragm due to change of temperature, may have an appreciable influence upon the amplitude of vibration. In other words, although the observed amplitudes are relatively large, and the precision of measurement is seemingly high, yet the system is in a virtually unstable condition. Consequently, although there is no reason to suppose that the conditions at resonance differ from those off resonance, nevertheless, when a reliable and reproducible set of observations of amplitude distribution is desired, it is advisable to select a frequency not too close to resonance, or say of about half the resonant amplitude.

Application of Circular Velocity-Diagram Theory to Results of Explorations.

It is shown in the first-approximation theory of Appendix II., that the behavior at the center of a flat-clamped circular diaphragm, subject to constant vibro-motive force of varying frequency, can be completely predicated, if three constants of the diaphragm are known;[4] namely,

(1) the "equivalent mass" m (gm.),

(2) the elastic constant s (dynes per cm. of displacement at center),

(3) the mechanical resistance r (dynes per unit velocity at center).

All these three constants can be obtained, for an acoustically excited diaphragm, with the aid of the vibration explorer.

Determination of m.

In order to determine the equivalent mass of a diaphragm, it is necessary to know the distribution of amplitude over the entire vibrating surface. As is shown in Appendix III., when the distribution of amplitude conforms regularly with the Rayleigh formula, it would appear that the equivalent mass is 0.183 times the mass of the circular vibrating plate. If, however, the distribution of amplitude is irregular, such as may be produced by bipolar electromagnetic excitation of a telephone-receiver diaphragm, the coefficient 0.183 cannot be depended upon, and the proper coefficient must be determined by some process of quadrature, such as Appendix III. describes.

The Elastic Constant s.

The constant s is the inferred elastic resisting force, which, acting perpendicularly upon the diaphragm's equivalent mass (at its center), would produce the same effect upon the vibratory motion as the distributed elastic forces produce upon the diaphragm's distributed mass, in the presence of the particular impressed force distribution. The simplest way to find s is to measure the natural fundamental frequency n_0 of the diaphragm, by exciting it with an

[4] See Bibliography No. 8.

organ-pipe of adjustable pitch, tuned to produce the maximum vibratory amplitude at the center. As shown in Appendix II., the constant s is then the product of the equivalent mass m and the square of the resonant angular velocity ω_0.

A series of statical measurements were made, by applying small tensions f_s, by means of a calibrated spring, to the center of the diaphragm, and observing, with the aid of the explorer, the central displacements w_s, thereby produced. It was found, as might be expected, that the ratio of f_s to w_s was constant, so long as the latter did not exceed 18μ. Moreover, the value of s obtained from f_s/w_s was approximately the same as that obtained from formula (9), App. II. This static method of finding s, however, is inferior to the resonance method, because precise static measurements are difficult to obtain. The application of electro-magnetic excitation to a steel diaphragm also imposes residual stresses, which make the use of the static method unreliable.

The Mechanical Resistance r.

The constant **r** was measured, with the explorer, by photographing the decay curve of vibration amplitude on a moving photographic film, when the diaphragm was tapped at the center, and allowed to return to the equilibrium position under its own damping forces. It is shown in Appendix II., that the resistance r is twice the natural frequency multiplied by the equivalent mass and the logarithmic decrement. Fig. 10 is a tracing from a photograph of

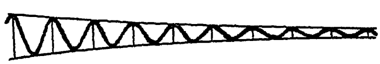


Fig. 10. Tracing from Photograph of Decay Curve. Diaphragm No. 1.

the curve of decay. A small camera, represented in Fig. 11, was set up in front of the explorer, containing a photographic film wrapped around a metal drum. The drum was motor driven at a peripheral speed of approximately 4 meters per second, and the shutter was opened at the time of tapping the diaphragm. The logarithmic decrement of this curve is 0.184, at the frequency of 824 ~; so that with an equivalent mass m of 1.09 gm. the value of

r becomes 328 dynes per cm. per sec. The precision in measuring r by this method is relatively low, owing to the difficulty in measuring the successive amplitudes with accuracy, on a curve of such small dimensions.

Since, as is shown in Appendix II., a circular diaphragm, in its fundamental mode of motion, ordinarily develops a circular graph of velocity, at varying impressed frequency, with constant vibro-

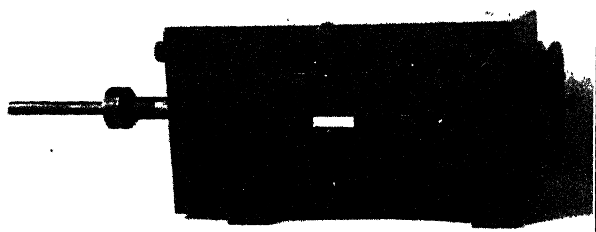


Fig. 11.
Sound-Wave Camera.

motive force, the plan has suggested itself, in the course of this research, to use the circle-velocity diagram of a diaphragm for comparing the vibro-motive forces (vmf.'s) of different organ-pipes. In this connection, the vmf. of a pipe at the exploring diaghragm, may be defined as its harmonically varying pressure $f = F\epsilon^{i\omega t}$ (dynes) produced, at the diaphragm, by the pipe, under the geometrical conditions of the system, including acoustic reflections from walls, or other objects in the room, on both surfaces of the exploring diaphragm. In the simplest, or standard, geometrical condition, the *standard* vmf., which is proportional to the square root of the sound intensity[5] at the diaphragm, would be observed in free space, with the orifice of the pipe facing the diaphragm at a definite distance, and with the diaphragm perpendicular to the line joining them. It is our understanding that there is, as yet, no simple published method of measuring the vmf. of organ pipes, of different

[5] Bibliography 6, Barton, "Text Book of Sound," p. 211, par. 146. Macmillan Co., 1908.

sizes or pitches, at a definite distance from their orifices. If, in a given geometrical environment, pipes of different pitches are set up, in succession, at the same position with respect to the exploring diaphragm, then the observed amplitudes, multiplied by the respective values of ω, should lie on the velocity circle-diagram, if the vmf.'s of the pipes are the same; assuming that the fundamental mode of vibration is produced, that the constants of the diaphragm remain unchanged, and that the overtones of the pipes are negligibly small. The vector departures from the circle diagram would then indicate the inequalities in vmf.'s.

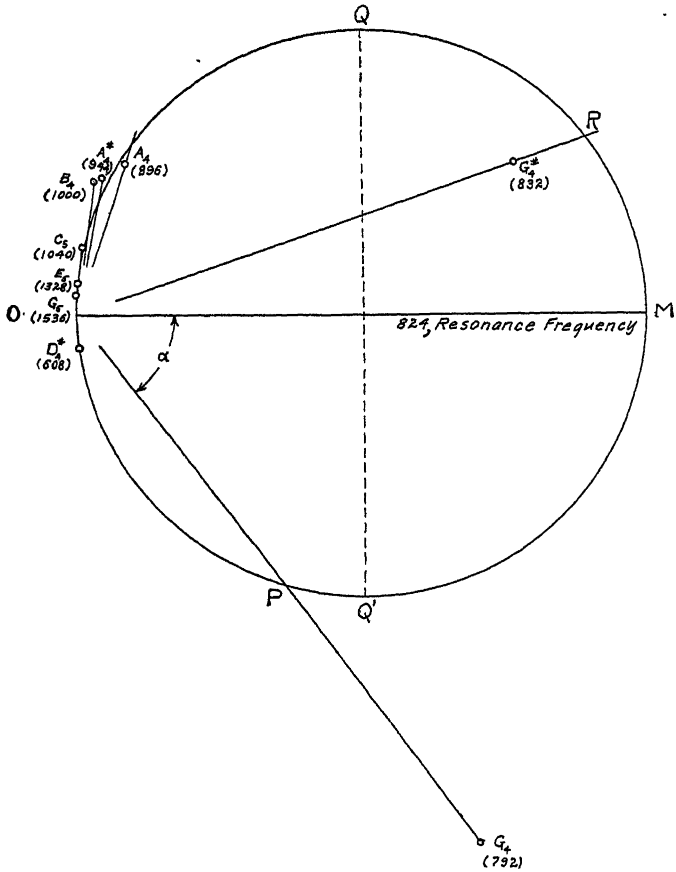


FIG. 12. Diagram Showing Strengths of Organ Pipes Given by the Vibration of a Diaphragm.

Fig. 12 is an inverted velocity-circle diagram for Diaphragm No. 1, based upon its measured values of m, $\mathbf{r}$ and s. If we take the diametral velocity OM as 5 cm. per sec., with $\mathbf{r}=328$ dynes per cm./sec., then the vmf. which, in the particular environment of the experiment, produced this velocity, would be 1,640 dynes, maximum cyclic value. The particular pipe $G_4(792 \sim)$, gave an observed amplitude at the diaphragm center, which, multiplied by $\omega = 2\pi \times 792$, gives the line OG_4 along the chord OP. The phase-angle α must be obtained by considering the mechanical reactance as in (4), App. II. If the vmf. of this pipe were the same as that which produced OM, this point G_4, would lie on the circle. Consequently, the vmf. of the pipe G_4 is to that of the pipe producing resonance, in the ratio OG_4/OP. Similarly, the vmf. of the pipe $G_4^{\#}(832 \sim)$, is less than that producing the resonant velocity, in the ratio $OG_4^{\#}/OR$. It is evident that the range of any one diaphragm, for the precise comparison of vmf.'s from organ-pipes of different pitch, is somewhat limited. In the case presented, it would not exceed one octave, since the chords far from the resonant diameter become so short. By selecting a diaphragm of relatively large damping constant $\Delta = \mathbf{r}/2m$, this range can be increased. In fact, the range in ω between the quadrantal points QQ' on the velocity circle, is numerically equal to $\mathbf{r}/m$, or twice the damping constant.

A succession of calibrated diaphragms with overlapping ranges might be employed to cover the musical scale. The writers have not attempted to compare organ-pipes for standard vmf. in this manner. The measurements might have to be made out-of-doors. In the sound-absorbing room in which this research was carried on, the effect of sound reflections from walls and other objects prevented any standard comparisons of vmf. from being made.

Explorations with Electromagnetically Excited Diaphragms.

In order to ascertain the effects of exciting a steel diaphragm (No. 2) electromagnetically, a No. 144 Western Electric Bell telephone receiver was screwed into the explorer, behind the diaphragm, so as to obtain the ordinary air-gap between the diaphragm and its two poles. The cap or screw-cover of the ordinary telephone re-

ceiver was here absent. Alternating current of 2 milliamperes (root-mean-square) was supplied from a Vreeland oscillator, giving a close approximation to a pure sine wave, and in connection with a Rayleigh bridge, for the simultaneous measurement of both the resistance and inductance of the telephone receiver, at 32 frequencies varying between 429 and 2,040 ∼. Explorations were

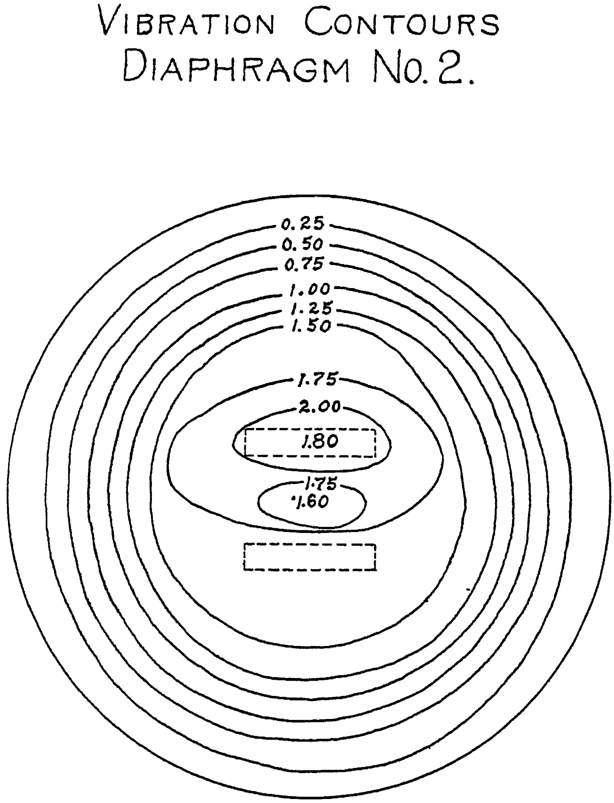


FIG. 13.

made at two frequencies; one, the resonant frequency of 992 ∼, and the other slightly below this, or 974 ∼. The contour lines for the latter case are presented in Fig. 13, where the outlines of the

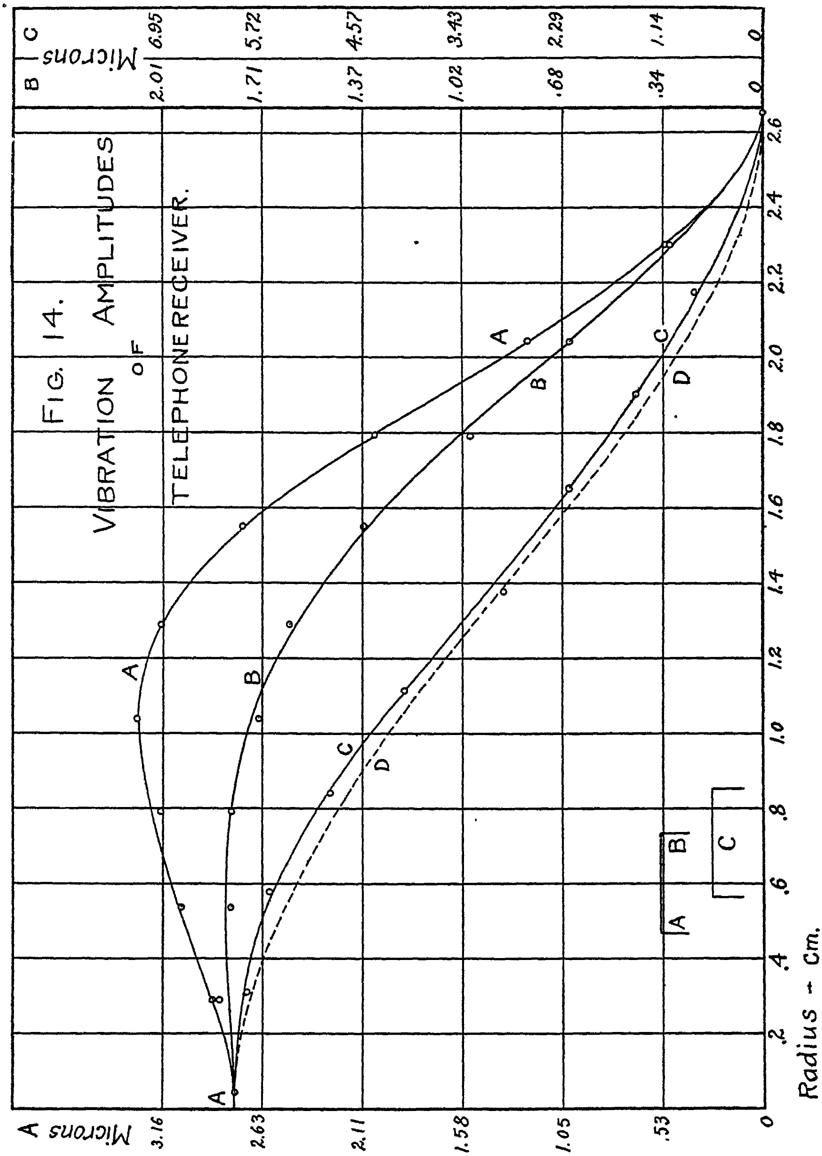


FIG. 14. VIBRATION AMPLITUDES OF TELEPHONE RECEIVER.

two magnetic poles are indicated in dotted lines. It will be seen that while the mode of motion is essentially fundamental, the amplitude is not a maximum at the center, as in the ordinary acoustic case. The maximum amplitude of $2.0\,\mu$ is reached in an elliptical loop embracing the pole at the top. Inside this loop, and immediately over the pole, the amplitude falls off to $1.8\,\mu$. Over the pole underneath, the amplitude is about $1.7\,\mu$, but there appears to be a slight diminution between the poles. If the geometrical and magnetic conditions of the bipolar system were perfectly symmetrical, these dissymmetries would presumably disappear.

The curves of mean amplitude against radial distance are presented in Fig. 14. The curve *AAA* corresponds to that found at resonance, and shows that the amplitude is far from being a maximum at the center of the diaphragm, owing to the attractive forces being established over polar areas on each side of the center. The coefficient of equivalent mass for this curve is over 0.5.

The curve *ABB* gives the corresponding distribution of mean azimuthal amplitude for the frequency of 974 ~. The swelling of the amplitude over the poles is less marked in this case, and does not materially exceed that at the center. The equivalent mass coefficient for this curve is 0.36, or about double that for the Rayleigh-Bessel curve case, which is indicated by *ADD*. The curve *ACC* gives the distribution of mean amplitude in radial distance, for another steel diaphragm (No. 3) in a bipolar telephone receiver, at the resonant frequency of 1,020 ~.

For both steel diaphragms Nos. 2 and 3, a series of central amplitude measurements were made, with the explorer, at constant alternating-current excitation, but adjustably varied frequency. Simultaneous measurements were made by Mr. H. A. Affel, of the resistance and inductance of the telephone-receiver coils, with the diaphragm both free and damped. The explorer measurements in both cases satisfactorily checked the electrically deduced velocity-circle diagrams. It is proposed to report upon the electrical measurements in another paper. Moreover, starting with the amplitudes, measured at the center of the diaphragm, in curves *A* and *C* of Fig. 14, the equivalent masses of the diaphragms, computed from the electrical measurements, agreed, within a few per cent., with those found by integrating curves *A* and *C*.

Temperature Effects.

It was found that changes of temperature in the air surrounding a diaphragm had a marked effect, both upon its resonance frequency, and upon its amplitudes at any frequency. The curves representing w against r, were apt to differ appreciably in outline from day to day. The degree of tightness of clamping also had a marked effect in these measurements. In general, such disturbances due to temperature and clamping, are likely to introduce tensions in the substance of the diaphragm, and to cause some of the characteristics of vibrating membranes to be superposed upon those of a vibrating plate. It is, therefore, desirable that the clamping should be effected tightly, and that the measurements should then be made before the temperature has changed. Strictly speaking, the Rayleigh theory shows that there must be a marked difference in both the resonance frequency and in the distribution of amplitudes, if the diaphragm is clamped between circular knife edges, instead of between circular flat rings at the boundary. The experiments have shown that flat-ring clamping is more likely to give consistent results than knife-edge clamping. These clamping difficulties are accentuated in thin glass diaphragms, for the boundary supporting of which, a special technique had to be developed.

Exploration of Thin Glass Diaphragms.

From a number of thin glass diaphragms, one Diaphragm No. 4, was selected, on account of its uniformity in thickness. See Table III. It was found very difficult to obtain uniform results with this in the explorer, owing to the above mentioned troubles with clamping. Finally, the glass diaphragm was cemented, with water glass, to a boundary ring of glass, and this was lightly supported between the clamping rings of the explorer. The diaphragm was then excited acoustically by organ-pipes. The natural pitch of the diaphragm was found to be 492 ~, in the fundamental mode. On raising the frequency, the mode of motion was found to change suddenly, at 968 ~, to that of a single nodal diameter, the two halves of the diaphragm then vibrating harmonically in opposite phases. This mode of motion continued until the frequency reached 1,696 ~,

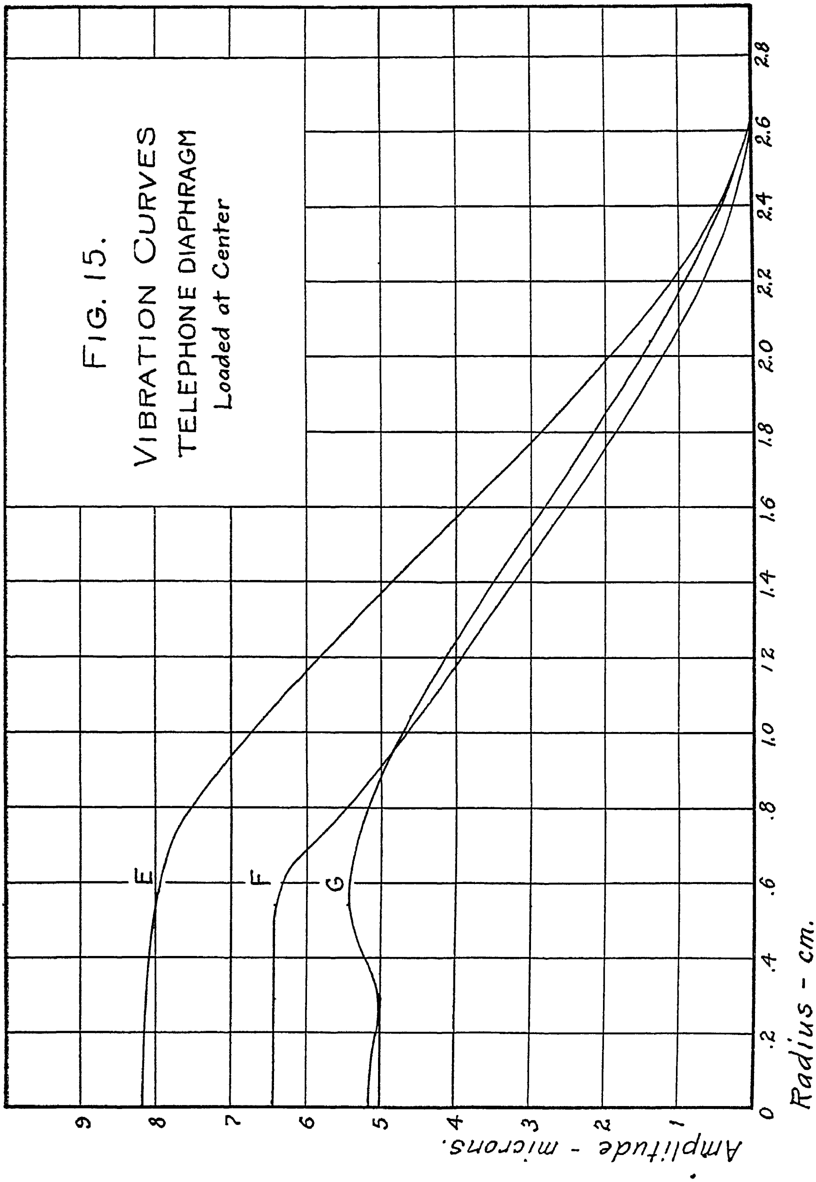


FIG. 15.
VIBRATION CURVES
TELEPHONE DIAPHRAGM
Loaded at Center

when the nodal diameter disappeared and gave place to a single nodal circle. The ratios of the above three frequencies are 1 : 1.97 : 3.44; whereas, according to the Bessel-function theory, they should be 1 : 2.09 : 3.91. The discrepancies may readily be accounted for by imperfections in boundary support, or by temperature effects. Small changes in clamping were found to exercise a marked influence on these ratios.

Loading of Diaphragm.

In the determination of m, r and s, by electrical impedance measurements,[6] only two quantitative relations between these three constants naturally present themselves; whereas, for the evaluation of these three unknowns, three independent quantitative relations must be experimentally obtained. It had been hoped to derive the missing third equation, by applying a small known load-mass at the center of the diaphragm, and by repeating the electrical measurements with this load in place. Electrical experiments showed, however, that while, occasionally, consistent results were obtained in this way, more often the results were discordant. The reason for the discordance has been shown, from explorations of the diaphragm, to be due to a distortion of the amplitude curves; whereby the equivalent mass of the loaded diaphragm is no longer the same as when unloaded.

These conditions are exhibited in the curves of Fig. 15. E shows the w, r curve, for an unloaded telephonic steel diaphragm, excited acoustically at $n = 904 \sim$, its natural frequency being $n_0 = 832 \sim$. The corresponding curve F is for the same diaphragm, after being loaded at the center by a small brass cylinder of 0.536 gm. at $n = 816 \sim$, its new natural frequency being $n_0 = 696 \sim$. After increasing the load to 1.08 gm., the new curve is shown at G ($n = 660 \sim$, $n_0 = 616 \sim$). The shapes of these three curves E, F and G, being so different, it is evident that the equivalent mass of the diaphragm by itself cannot be regarded as constant.

The authors are indebted to Dr. Geo. A. Campbell for a number of valuable suggestions which he made after having read the MSS. of this paper; also to Professor W. C. Sabine for very useful suggestions, during the course of the research.

[6] Bibliography No. 8.

SUMMARY.

1. The distribution of amplitudes over small circular telephonic diaphragms, under simple impressed vibrations, has been measured, it is believed for the first time, by means of a new and specially constructed vibration-explorer.

2. The simple vibrations of the small steel circular diaphragms, used in telephonic receivers, appear to belong to the fundamental mode, within the ordinary telephonic range of intensity and frequency up to 2,000 ~, with the distribution of impressed forces here described.

3. The explorations have confirmed the working theory of the velocity-circle diagram for such vibrations, and have afforded means of determining the three constants m, r and s, in that theory, for acoustically excited vibrations.

4. In the resonant condition, exploration is somewhat uncertain, owing to slight instability in the vibratory behavior of the diaphragm.

5. The distribution of forced amplitude at varying radial distances, has been found to compare well with the Rayleigh theory of freely vibrating plates, when good flat clamping around the edge can be secured, and with acoustic excitation. The coefficient of equivalent mass appears to be 0.183 for such a case. With electromagnetic excitation, the amplitude distribution may be very different and the coefficient is ordinarily increased.

6. Loading a diaphragm with a small mass at the center, decreases its natural frequency, and tends to reduce the amplitude of vibration at the center, with a relative increase at outlying points; so that the equivalent mass of the diaphragm, considered by itself, is apt to be changed.

7. A means is suggested, based on the velocity-circle diagram, for comparing the acoustic intensities of organ-pipes of different pitches.

8. The distribution of amplitudes over the surface of a steel receiving-telephone diaphragm, with bipolar electromagnetic excitation, was found to be of fundamental mode, but with a tendency to form two maxima, one over each pole.

9. In some small, thin, glass diaphragms, three modes of vibra-

tory motion were observed, in the range of acoustic impressed frequency up to 1,700 ~.

TABLE III.

FLAT CIRCULAR DIAPHRAGMS.

No.	Material.	Diameter, Cm.	Thickness* Over Japan, Cm.	Mass, Gm.	Natural Frequency ~.
1	Steel japanned......	5.4	0.038	5.615	824
2	Steel japanned......	5.52	0.0399	5.979	992
3	Steel japanned.....	5.48	0.031	4.181	1020
4	Glass.............	5.4	0.0108	0.6548	492

APPENDIX I.

Application of Bessel-Function Theory to a Diaphragm Vibrating in its Fundamental Mode.

Referring to Lord Rayleigh's "Theory of Sound," Vol. 1, page 352, the formula for the instantaneous amplitude of free vibration in a flat plate is,

$$w_n = P\{J_n(kr) + \lambda J_n(ikr)\}\cos(n\theta + \alpha_n)\cdot\cos(\omega t + e) \quad \text{cm.,} \quad (1)$$

where subscript n = the number of nodal diameters (numeric),

w_n = instantaneous amplitude at a point on the diaphragm whose polar coördinates are r cm., θ radians (cm.)

P = constant of amplitude-magnitude (cm.),

k = a constant of the material defined by:

$k = \sqrt{\omega}/c$ (cm.$^{-1}$),

c = a constant of the material defined by:

$$c = \sqrt[4]{\frac{qb^2}{12\rho(1-\sigma^2)}} \qquad (\text{cm./sec.}^{\frac{1}{2}}),$$

q = Young's modulus for the diaphragm material (dyne/cm.^{2}),

ρ = density of the diaphragm material (gms./cm.^{3}),

σ = Poisson's ratio for the diaphragm material (numeric),

b = thickness of the diaphragm (cm.),

λ = a constant satisfying boundary conditions (numeric),

J_n = a Bessel's Function of the nth order (numeric),

$i = \sqrt{-1}$,

* Thickness of japan 0.0074 cm.

α_n = a phase-angle measured around the diaphragm (radians),
$\omega = 2\pi n$ = angular velocity of vibrating motion (radians/sec.),
n = frequency of diaphragm vibration (cycles/sec.),
t = time elapsed from a given epoch (seconds),
e = a time-phase determined by the epoch (seconds),
a = radius of the diaphragm (cm.).

For the fundamental mode of motion, $n = 0$; or there must be no nodal diameters. Consequently (1) reduces to:

$$w_0 = P\{J_0(kr) + \lambda J_0(ikr)\} \cos(\omega t + e) \qquad \text{cm. (2)}$$

Here the amplitude of vibration at any point w_0, ceases to be a function of θ, and depends only on Bessel functions of r. Since we shall consider only the fundamental mode of vibration in what follows, the subscript will be unnecessary, and we may substitute w for w_0.

Continuing Lord Rayleigh's method of demonstration, if a flat circular diaphragm is clamped at its edge between a pair of flat circular rings, then, referring to (2), we have w vanishing at $r = a$, the clamping radius, and since there is to be no bending or slope of the diaphragm at the clamped boundary, we have also $(dw/dr) = 0$ at $r = a$.

Entering (2) with $w = 0$, we have:

$$\lambda = -\frac{J_0(ka)}{J_0(ika)} \qquad \text{numeric. (3)}$$

Also differentiating (2) with respect to r, for $r = a$, we obtain:

$$\frac{1}{k}\frac{dw}{dr} = J_0'(ka) + i\lambda J_0'(ika) = 0 \qquad \text{numeric, (4)}$$

whence

$$\lambda = -\frac{J_0'(ka)}{iJ_0'(ika)} \qquad \text{numeric. (5)}$$

Combining (3) and (5) we obtain:

$$\frac{J_0(ka)}{J_0(ika)} = \frac{J_0'(ka)}{iJ_0'(ika)} = \frac{J_1(ka)}{iJ_1(ika)} \qquad \text{numeric. (6)}$$

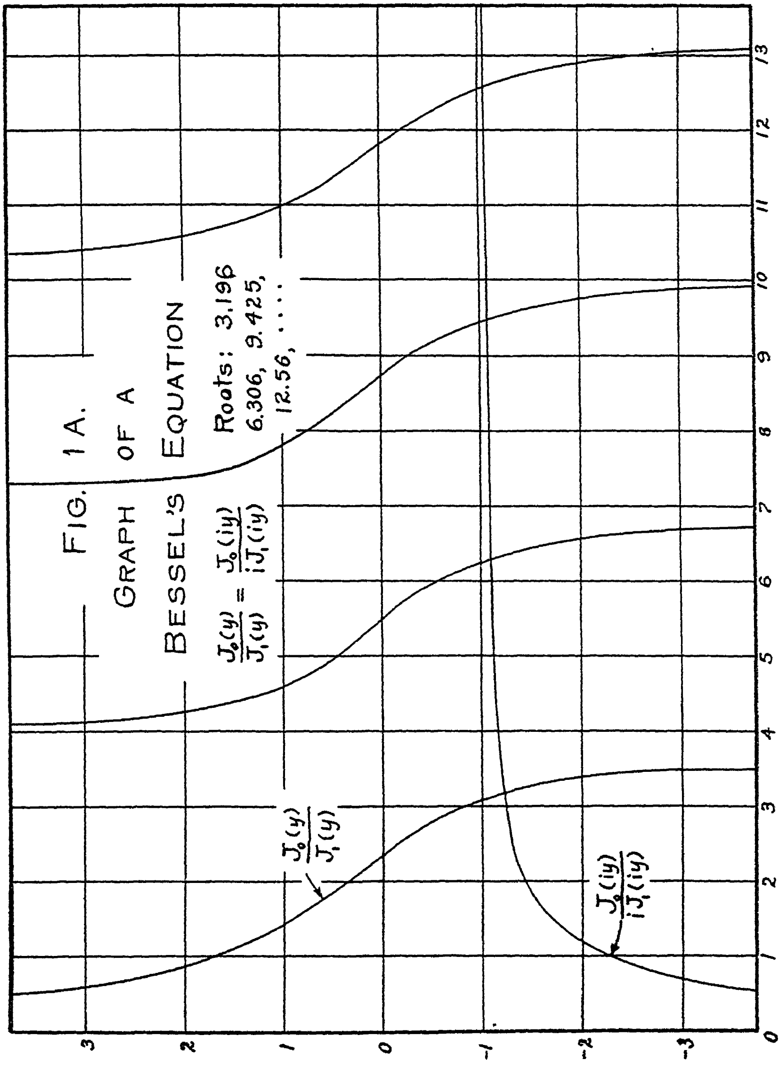


FIG. 1A.
GRAPH OF A BESSEL'S EQUATION
$\frac{J_0(y)}{J_1(y)} = \frac{J_0(iy)}{iJ_1(iy)}$
Roots: 3.196, 6.306, 9.425, 12.56, ...
$\frac{J_0(y)}{J_1(y)}$
$\frac{J_0(iy)}{iJ_1(iy)}$
3
2
1
0
-1
-2
-3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
$y \longrightarrow$

This is a transcendental equation involving Bessel's Functions of the zeroth and first orders. It is capable of being satisfied, by trial, with an indefinitely great number of roots, each corresponding to a possible mode of vibration with nodal circles. Fig. 1*A* indicates graphically the method of determining the successive roots of (6). The points of intersection of the lower curve with the successive descending branches, indicate the values of $y = kr$ which satisfy (6). In order to have the fundamental mode of vibration, there must be no nodal circles, which means that the first and lowest root for ka must be taken in (6). This root is at $ka = 3.196 \ldots$ Placing this value for ka in (3) we have:

$$\lambda = \frac{-J_0(3.196)}{J_0(i3.196)} = -\frac{-0.3197}{5.730} = +0.05571 \quad \text{numeric.} \quad (7)$$

Re-entering (2) with this value of λ, we have for the fundamental mode of vibration of the circular diaphragm:

$$w_{\max} = P\{J_0(kr) + 0.05571 J_0(ikr)\} \qquad \text{cm.} \quad (8)$$

In Fig. 1*B*, the abscissas correspond both to kr, where $k = 1.21$ cm.$^{-1}$, and to r in cm., the relation being as already pointed out that at the boundary $r = a = 2.62$ cm. and $kr = 3.196$. The ordinates are the numerical values of Bessel's functions as taken from Tables. They also represent vibratory amplitudes of the diaphragm, taking the maximum amplitude at the center ($r = 0$) in microns, corresponding to the heavy curve. The upper faint curve shows the graph of the first Bessel function $J_0(kr)$; while the lower faint curve shows the corresponding graph of λ times the second Bessel function, or $0.05571 J_0(ikr)$. Adding these two graphs, as called for by (2), we obtain the heavy curve, which represents the theoretical amplitude of vibration along any radius of this particular diaphragm, assuming such a scale that 1.056 corresponds to the maximum or central amplitude. The small circles near this curve show the amplitudes observed with the aid of the vibration explorer.

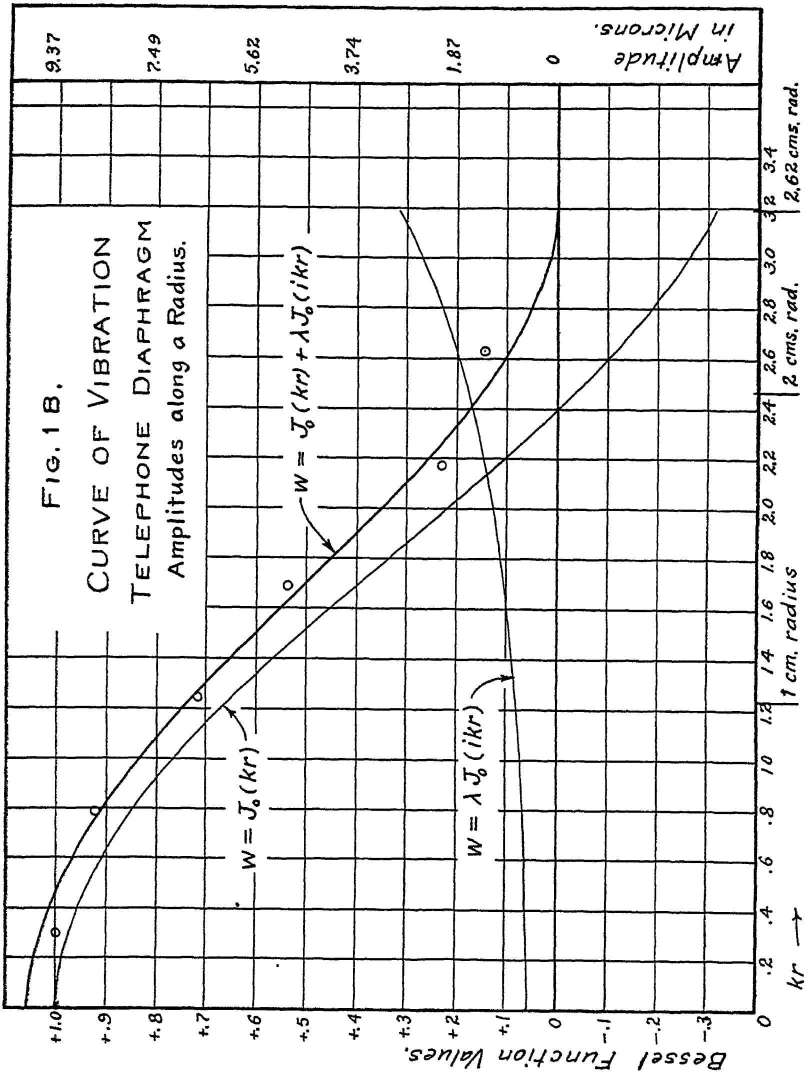


Fig. 1 B.
Curve of Vibration
Telephone Diaphragm
Amplitudes along a Radius.
$W = J_0(kr) + \lambda J_0(ikr)$
$W = J_0(kr)$
$W = \lambda J_0(ikr)$
Amplitude in Microns.
9.37
7.49
5.62
3.74
1.87
0
Bessel Function Values.
+1.0
+.9
+.8
+.7
+.6
+.5
+.4
+.3
+.2
+.1
0
−.1
−.2
−.3
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
$kr \rightarrow$
1 cm. radius
2 cms. rad.
2.62 cms. rad.

Appendix II.

Elementary Theory of the Steady Vibration Amplitude of a Diaphragm Vibrating in its Fundamental Mode, as a Function of the Impressed Frequency.

Let w = the vibration amplitude at the center of the diaphragm[8] (cm. $\angle$),

w_r = the vibration amplitude at the radius r (cm. $\angle$),

$\dot{w}$ = the vibration velocity at the center of the diaphragm (cm./sec. $\angle$),

$\ddot{w}$ = the vibration acceleration at the center of the diaphragm (cm./sec.^{2} $\angle$),

r = frictional resistance to motion of the diaphragm, referred to the equivalent mass, see below (dynes/cm. per sec. $\angle$),

t = elapsed time from a given epoch (seconds),

s = elastic force of the diaphragm per cm. of displacement, referred to the equivalent mass (dynes per cm. $\angle$),

$f = Fe^{i\omega t}$ = impressed simple harmonic moving force on the diaphragm tending to produce displacement w, and measured in the direction of w, referred to the equivalent mass (dynes $\angle$),

$i = \sqrt{-1}$,

$\omega = 2\pi n$ = the angular velocity of a simple harmonic motion of frequency n (radians/sec.),

m = equivalent mass of the diaphragm, defined by the condition that the energy of motion of this mass with the velocity $\dot{w}$ at the center, is equal to the actual energy of the diaphragm with its distributed mass and velocities, according to the equation:

$$\frac{m}{2}(\dot{w})^2 = \frac{2\pi\rho'}{2}\int_0^a r(\dot{w}_r)^2 dr \qquad \text{ergs,} \quad (1)$$

where ρ' = superficial density of the diaphragm (gm./cm.^{2}),

$$m = \frac{2\pi\rho'}{w_{\max}^2}\int_0^a (w_r)^2 r dr \qquad \text{gm.,} \quad (2)$$

[8] The sign $\angle$ after a unit indicates a "complex quantity."

since the velocities $\dot{w}$ and $\dot{w}_r$ being assumed simply harmonic, are respectively proportional to their maximum displacements w_{max} and w_r.

Then on the assumptions that the diaphragm vibrates like its equivalent mass collected at the center, with its observed central velocity, with an elastic opposing force sw on this mass, proportional to the displacement, and with a resisting force $\mathrm{r}\dot{w}$ on this mass proportional to the velocity, then the equation of motion of the diaphragm in terms of equivalent mass will be[9]

$$sw + \mathrm{r}\dot{w} + m\ddot{w} = f = F\epsilon^{i\omega t} \qquad \text{dynes} \angle. \quad (3)$$

The solution of this equation, in terms of velocity $\dot{w}$, and the steady state, is known to be

$$\dot{w} = \frac{f}{\mathrm{r} + i\left(m\omega - \frac{s}{\omega}\right)} = \frac{f}{\mathrm{r} + ix} = \frac{f}{z} = \frac{F}{z}\epsilon^{i\omega t} \qquad \frac{\text{cm.}}{\text{sec.}} \angle, \quad (4)$$

where x is the "mechanical reactance," and z is the complex "mechanical impedance," by analogy to alternating electric current theory. Both x and z have the same dimensions as r.

The mechanical impedance relations are indicated in Fig. II*A* at the left-hand side. OX and OY being rectangular coördinates, the "mechanical resistance" r in dynes per unit velocity, is measured along OX, and is assumed to remain constant at all frequencies. As the frequency n is increased (and with it the vibratory angular velocity ω) from zero to infinity, the reactance $x = (m\omega - s/\omega)$ varies from $-\infty$ to $+\infty$ along the line yXy'. The mechanical impedance z which is the vector sum of r and ix, will be represented by a complex quantity, or plane vector Op, the extremity of which remains on the line yXy'. At the particular or resonant value of ω, for which $m\omega - s/\omega = 0$, the reactance vanishes, and the impedance z coincides with the resistance r. As shown in the figure, p lies above OX, corresponding to a value of ω somewhat greater than the critical or resonant value.

[9] See Bibliography No. 8.

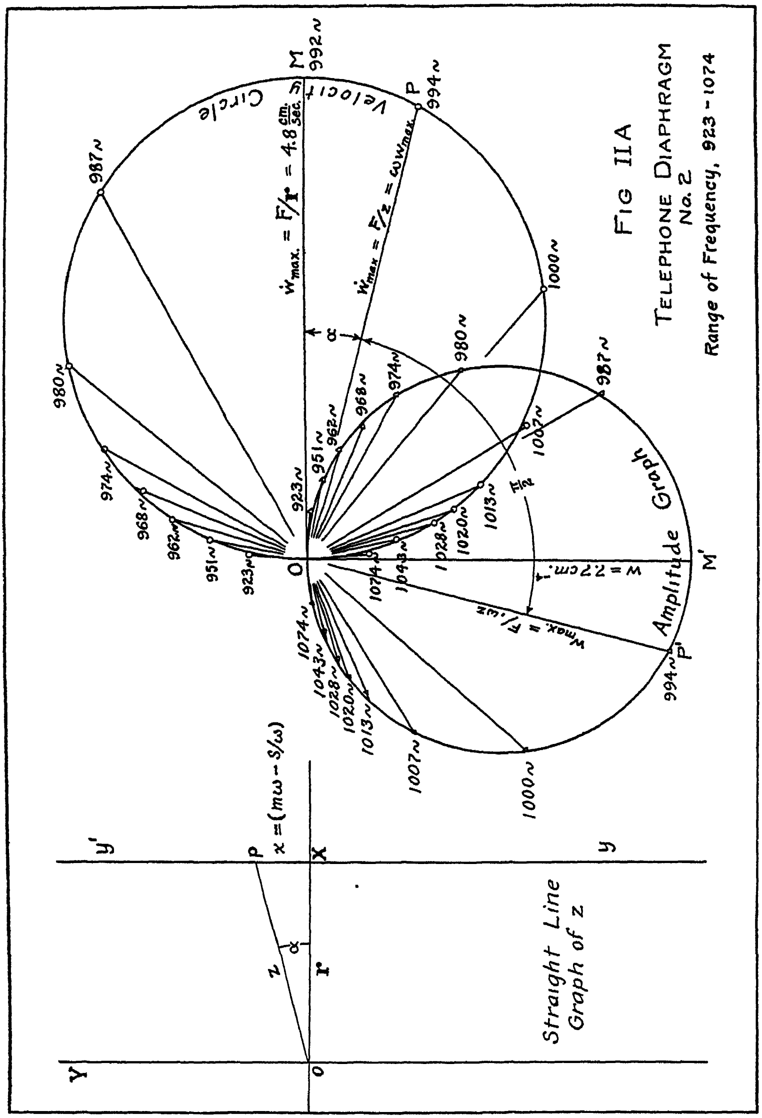


FIG IIA
TELEPHONE DIAPHRAGM
No. 2
Range of Frequency, 923 - 1074

Equation (4) shows that the displacement velocity $\dot{w}$ is equal to the impressed vibro-motive force f, divided by the impedance z. The locus of this velocity, as ω varies from 0 to ∞ with constant F, becomes a circle OMP, the diameter OM of which is equal to F/r cm. per sec., while the angle α of the chord OP, measuring the velocity, is equal and of opposite sign to the angle α of the impedance z. In the case represented by Fig. IIA, the telephone diaphragm No. 2 was actuated electromagnetically at constant alternating-current strength, under varying frequency. At the frequency $n = 992 \sim$, the vibratory velocity $OM = 4.8$ cm. sec., was a maximum, and was in phase with the impressed vibro-motive force F. At $n = 994 \sim$, the mechanical impedance had increased to op at the angle $\alpha = 14°$, and the vibratory velocity had fallen from OM to OP or from 4.8 to 4.65 cm. per sec. lagging in phase behind the impressed vibro-motive force by 14°. The diagram shows that between the frequencies of 923 and 1,074 $\sim$, the vector displacement velocity $\dot{w}$ had moved over nearly the entire circumference of the velocity circle OMP, and from a phase nearly 90° ahead of the impressed vibro-motive force to nearly 90° behind it.

If we integrate (4) with respect to time, we obtain, for the steady state of motion,

$$w = \int \dot{w} dt = \int \frac{F\epsilon^{i\omega t}}{z} dt = \frac{F\epsilon^{i\omega t}}{i\omega z} = -\frac{iF\epsilon^{i\omega t}}{\omega z}, \qquad \text{cm.} \angle. \quad (5)$$

This shows that the instantaneous displacement is ω times less than the corresponding instantaneous velocity, and is 90° behind it in phase. If we consider the maximum displacement, we have

$$w_{\max} = -\frac{iF}{\omega z} \qquad \text{cm.} \quad (6)$$

The locus of $w_{\max}$ is therefore a closed curve distorted from a circle by the effect of varying ω in the denominator. Considering it as an approximate circle for this case, the diameter OM' corresponding to $n = 992 \sim$ represents a displacement amplitude of $7.7\,\mu$, lagging approximately 90° behind the maximum velocity OM. At the frequency 994 $\sim$, the displacement would be $OP' = 7.48\,\mu$,

lagging 90° behind OP. As the frequency varies between 923 and 1,074 ~, the displacement amplitude almost covers the entire graph of the approximate circle $OM'P'$, commencing at about 1 μ, nearly in phase with the vibro-motive force, and ending at about 1 μ in nearly opposite phase. These amplitudes correspond to the ordinates of the resonance curve in Fig. 9.

It follows from (4) that if the vibro-motive force f is kept constant, and the angular velocity adjusted until the central vibration velocity is a maximum, this will occur when the mechanical reactance is zero, or when

$$m\omega_0 - \frac{s}{\omega_0} = 0 \qquad \frac{\text{dynes}}{\text{cm./sec.}}, \qquad (7)$$

that is

$$\omega_0 = \sqrt{\frac{s}{m}} \qquad \frac{\text{radians}}{\text{sec.}}. \qquad (8)$$

So that

$$s = m\omega_0^2 \qquad \frac{\text{dynes}}{\text{cm.}}. \qquad (9)$$

When the vibro-motive force f is made to vanish in (3) with the diaphragm in motion, the solution of the equation is

$$w = W\epsilon^{-\frac{rt}{2m}} \sin(\omega t + e) \qquad \text{cm.}, \qquad (10)$$

where W is the initial displacement (cm), and e a suitable phase (radians). If we obtain two successive values of w, (w_1 and w_2), corresponding to two successive elongations in the same direction, we have

$$\frac{w_1}{w_2} = \epsilon^{r/2mn} = \epsilon^{\Delta/n} \qquad \text{numeric}, \qquad (11)$$

whence

$$r = 2mn \log_\epsilon (w_1/w_2), \qquad \text{dynes/(cm./sec.)}, \qquad (12)$$

where Δ is the damping constant (1/sec.).

The quantity $\log_\epsilon (w_1/w_2)$ is well known as the logarithmic decrement of the decay curve.

Appendix III.

Elementary Theory of Equivalent Mass.

In (2) of Appendix II., the expression for equivalent mass m is

$$m = \frac{2\pi\rho'}{w^2_{max}} \int_0^a w_r^2 \cdot r \quad dr \qquad \text{gm.} \quad (1)$$

or m is the mass which, vibrating at the center of the diaphragm with the observed maximum ampltiude w_{max}, would have the same kinetic energy as the total distributed kinetic energy of the diaphragm.

In order, therefore, to determine the equivalent mass of a diaphragm, it is necessary to integrate r times the square of the amplitude over its surface. Assuming that the vibration follows Rayleigh's Bessel-function theory as outlined in Appendix I., it should be sufficient to integrate $w_r^2 \cdot r$ over the surface, mathematically. We are indebted to Dr. Geo. A. Campbell for an indication of the solution of this integral.[10]

In (1)

$$w'_{max} = P[J_0(0) + \lambda J_0(i0)] = P(1 + \lambda) \qquad \text{cm.} \quad (2)$$

by reference to (8) Appendix I., putting $r = 0$.
Also

$$w_r = P[J_0(kr) + \lambda J_0(ikr)] \qquad cm. \quad (3)$$

$$\therefore m = \frac{2\pi\rho'}{P^2(1+\lambda)^2} \int_0^a P^2\{J_0^2(kr) + \lambda^2 J_0^2(ikr) + 2\lambda J_0(kr) J_0(ikr)\} rdr \quad (4)$$

$$= \frac{2\pi\rho'}{(1+\lambda)^2} \left[\int_0^a J_0^2(kr) r \cdot dr + \int_0^a \lambda^2 J_0^2(ikr) r \cdot dr + \int_0^a 2\lambda J_0(kr) J_0(ikr) r \cdot dr \right]$$

$$= \frac{2\pi\rho'}{(1+\lambda)^2} \left[\frac{a^2}{2} \{J_0^2(ka) + J_1^2(ka)\} + \frac{\lambda^2 a^2}{2} \{J_0^2(ika) + J_1^2(ika)\} + \frac{2\lambda a}{k^2 - i^2k^2} \{kJ_0(ika)J_1(ka) - ikJ_0(ka)J_1(ika)\} \right], \quad (5)$$

[10] Bibliography (11), (12), (13).

where

$$J_0^2(kr) \text{ stands for } \{J_0(kr)\}^2.$$

But $M = \pi\rho' a^2$ is the total mass of the vibrating diaphragm area.

$$\therefore \frac{m}{M} = \frac{1}{(1+\lambda)^2}\Big[\{J_0^2(ka) + J_1^2(ka)\} + \lambda^2\{J_0^2(ika) + J_1^2(ika)\} \\ + \frac{2\lambda}{ak}\{J_0(ika)J_1(ka) - iJ_0(ka)J_1(ika)\}\Big]. \tag{6}$$

Applying the ratios of (6) Appendix I., this reduces to:

$$\begin{aligned} \frac{m}{M} &= \frac{1}{(1+\lambda)^2} \cdot 2J_0^2(ka) \\ &= \frac{1}{(1.05571)^2} \cdot 2J_0^2(3.196) \\ &= \frac{0.20378}{1.1145} \\ &= 0.18285 \end{aligned}$$

or, to three significant digits, 0.183.

The "equivalent mass coefficient," 0.183, for this diaphragm, had also been obtained by quadrature methods applied to the heavy curve in Fig. 1*B*, before the integration was performed as above.

In the case of steel telephone diaphragms excited by bipolar electromagnets, the curves of w_r, r are likely to depart from simple Bessel-function curves, see Fig. 14. In such cases, the coefficient of equivalent mass must be deduced from the exploration curve. In cases examined, this coefficient varied between 0.2 and 0.5.

A quadrature method employed to find the equivalent mass coefficient from curves of any shape is as follows:

Draw the w_r curve as in Fig. 1*B*. Divide the line of abscissas into an integral number n of annular rings of equal area; so that each ring will have a mass of M/n, where M is the total mass of the circular vibrating area of the diaphragm, in grams. We then multiply this annular mass into the square of the observed amplitudes at the middle points of the successive annuli. The sum of these terms will be equal to the product of the equivalent mass m,

TABLE IV.

	kr	w	w (ave.)	w^2 (ave.)
	.0000	1.0557		(1.1145)
1	.4511	1.008	1.032	1.0650
2	.6380	.962	.985	.9702
3	.7814	.918	.940	.8836
4	.9023	.875	.897	.8046
5	1.009	.833	.854	.7293
6	1.105	.792	.812	.6593
7	1.194	.752	.772	.5960
8	1.276	.713	.732	.5358
9	1.353	.677	.695	.4830
10	1.427	.641	.659	.4343
11	1.496	.606	.624	.3894
12	1.563	.572	.589	.3469
13	1.627	.539	.555	.3080
14	1.688	.507	.523	.2735
15	1.747	.477	.492	.2421
16	1.805	.449	.463	.2144
17	1.860	.421	.435	.1892
18	1.914	.394	.408	.1665
19	1.966	.367	.380	.1444
20	2.018	.341	.354	.1253
21	2.067	.318	.330	.1089
22	2.116	.295	.307	.0942
23	2.163	.273	.284	.0807
24	2.210	.251	.262	.0686
25	2.256	.232	.242	.0586
26	2.300	.213	.223	.0497
27	2.344	.195	.204	.0416
28	2.387	.178	.186	.0346
29	2.429	.162	.170	.0289
30	2 471	.146	.154	.0237
31	2.512	.131	.139	.0193
32	2.552	.117	.124	.0154
33	2.592	.104	.110	.0121
34	2.631	.092	.098	.0096
35	2.669	.080	.086	.0074
36	2.707	.070	.075	.0056
37	2.744	.060	.065	.0042
38	2.781	.050	.055	.0030
39	2.817	.041	.045	.0020
40	2.853	.033	.037	.0014
41	2.889	.026	.030	.0009
42	2.924	0.21	.023	.0005
43	2.958	.016	.019	.0004
44	2.992	.012	.014	.0002
45	3.026	.009	.011	.0001
46	3.060	.006	.008	.00006
47	3.093	.004	.005	.00002
48	3.126	.002	.003	.000009
49	3.158	.001	.001	.000001
50	3.196	.000	.000	.000000
				10.2325

$$m = (M/50)\,(10.2325/1.1145) = .183\,M.$$

and the square of the maximum observed amplitude at the center, or

$$m = \frac{M}{n} \frac{\Sigma w_r^2}{w_{\text{max}}^2} \quad \text{gm.} \quad (7)$$

The preceding table sets forth this process for the curve of Fig. 1*B*, drawn theoretically, and checked observationally, with $n = 50$, or the diaphragm divided into 50 annuli of equal mass. The result is that the equivalent mass is 18.3 per cent. of the actual mass of the vibrating area. This result checks that obtained from the mathematical integration of the Bessel curve.

Although 50 annuli of equal area and mass were taken in the case above worked out, so as to attain a fairly high degree of precision in the evaluated equivalent-mass coefficient; yet, for many purposes, a sufficient degree of precision might be attained by taking only 10 such equal annular areas.

BIBLIOGRAPHY.

1. Rayleigh, "Theory of Sound," Vol. 1, p. 352, Macmillan Co., 1894.
2. R. Kempf-Hartmann, Ann. de Physik, 8, pp. 481–538, June, 1902.
3. W. Wien, Ann. de Physik, 18. S, pp. 1049–1053, December, 1905.
4. Henri Abraham, Comptes Rendus, Vol. 144, 1907.
5. Frederick K. Vreeland, Phys. Review, Vol. 27, p. 286, 1908.
6. Barton, "Text-Book of Sound," p. 211, Sec. 146, Macmillan Co., 1908.
7. Chas. F. Meyer and J. B. Whitehead, Trans. A. I. E. E., Vol. 31, II., pp. 1397–1418, 1912.
8. A. E. Kennelly and G. W. Pierce, "The Impedance of Telephone Receivers as Affected by the Motion of Their Diaphragms," Proc. Am. Acad. of Arts and Sci., Vol. 48, No. 6, September, 1912, p. 138; also *Electrical World,* September 14, 1912.
9. L. Bouthillon and L. Drouet, La Révue Electrique, October 16, 1914 (pub. January 15, 1915).
10. Augustin Guyau, "Le Téléphone Instrument de Mésure," Gauthier-Villars, Paris, 1914.
11. E. Jahnke and F. Emde, "Funktionentafeln mit Formeln und Kurven," p. 166 (3) and (4).
12. Paul Schafheitlin, "Die Theorie der Besselschen Funktionen," pp. 68 and 69.
13. W. E. Byerly, "Fourier's Series and Spherical Harmonics," p. 233.

TABLE OF SYMBOLS.

a = Radius of the diaphragm clamping-circle (cm.),
α_n = A phase angle measured around the diaphragm (radians),
b = Thickness of the diaphragm (cm.),
c = A constant of the material of the diaphragm (cm./second ½),
d = Sign of differentiation
Δ = Damping constant $= n \log_\epsilon (w_1/w_2) = \mathrm{r}/2m$ (second^{-1}),
e = Time-phase (radians),
ϵ = Naperian logarithmic base (numeric),
$f = F\epsilon^{i\omega t}$ Impressed simple harmonic moving force on the diaphragm (dynes) $\angle$
f_s = Statical tension (dynes),
F = Maximum value of a vibratory force (dynes),
$i = \sqrt{-1}$ (numeric),
J_n = A Bessel's Function of the nth order (numeric),
J' = The first derivative of J with respect to r (numeric),
k = A constant of the material of the diaphragm, defined by $k = (\sqrt{\omega})/c$ (cm.$^{-1}$),
L = Distance from mirror to scale of explorer (cm.),
l = Radius arm of small mirror in explorer (cm.),
λ = A constant satisfying boundary conditions (numeric),
M = Total mass of diaphragm (in Appendix III) (gm.),
M = Magnification factor of explorer (numeric),
m = Equivalent mass of the diaphragm (gm.),
μ = Micron, 10^{-4} cm. (cm^{-4}),
n = Frequency of diaphragm vibration (cycles/second),
n_0 = Resonant frequency of diaphragm vibration (cycles/sec),
n = Number of annular rings in equivalent mass theory of App. III (numeric),
n (Subscript) = Number of nodal diameters (order of Bessel's Function) (numeric),
P = Constant of amplitude-magnitude (cm.),
π = 3.1416 (numeric),
ϕ = Angle in the explorer between the plane of mirror and plane of diaphragm (deg.),
q = Young's modulus for diaphragm material (dynes/cm.^{2}),
r = Frictional resistance to motion of diaphragm $\frac{\text{dynes}}{\text{cm./sec.}}$,

r = Distance along a radius (cm.),
ρ = Density of diaphragm material (gm./cm.^{3}),
ρ' = Superficial density of diaphragm (gm./cm.^{2}),
s = Elastic force of diaphragm per centimeter of displacement, referred to equivalent mass (dynes/cm.),
σ = Poisson's ratio for material of diaphragm (numeric),
Σ = Sign of summation,
t = Time elapsed from a given epoch (seconds),
θ = Azimuth angle measured on surface of diaphragm (radians)
vmf. = Vibro-motive force (dynes) $\angle$,
W = Initial displacement in a vibratory motion (cm.),
w and w_0 = Amplitude of a point on surface of diaphragm for fundamental mode of vibration (cm.) $\angle$,
w_r = Amplitude of vibration of a point at radius r from center of diaphragm (cm.) $\angle$,
w_n = Instantaneous amplitude of vibration (cm.),
$w_{\max}$ = Maximum cyclic amplitude at center (cm.),
$\dot{w}$ = Vibratory velocity at center of diaphragm (cm./sec.) $\angle$,
$\ddot{w}$ = Vibratory acceleration at center of diaphragm (cm./sec.^{2}) $\angle$,
w_s = Statical displacement of center of diaphragm (cm.),
$ix = i(m\omega - s/\omega)$ "Mechanical reactance" of vibrating diaphragm (by analogy to alternating-current theory) {dynes/(cm./sec.)} $\angle$,
$z = (\mathrm{r} + ix)$ "Mechanical impedance" of vibrating diaphragm (by analogy to alternating-current theory) {dynes/(cm./sec.)} $\angle$,
$\omega = 2\pi n$ = Angular velocity of vibratory motion (radians/sec.),
$\omega_0 = 2\pi n_0$ = Angular velocity at resonance (radians/sec.),
∞ = Infinity,
$\angle$ = This sign after a unit indicates a "complex quantity,"
$\sim$ = Cycles or vibrations per second (cycles/sec.).

THE RULING AND PERFORMANCE OF A TEN INCH DIFFRACTION GRATING.

By A. A. MICHELSON.

(*Read April 22, 1915.*)

The principal element in the efficiency of any spectroscopic appliance is its resolving power—that is, the power to separate spectral lines. The limit of resolution is the ratio of the smallest difference of wave-length just discernible to the mean wave-length of the pair or group. If a prism can just separate or resolve the double yellow line of sodium its limit of resolution will be $\frac{5896-5890}{5893}$ or approximately one one thousandth, and the resolving power is called one thousand.

Until Fraunhofer (1821) showed that light could be analyzed into its constituent colors by diffraction gratings this analysis was effected by prisms the resolving power of which has been gradually increased to about thirty thousand. This limit was equalled if not surpassed by the excellent gratings of Rutherford, of New York, ruled by a diamond point on speculum metal, with something like 20,000 lines, with spacing of 500 to 1,000 lines to the millimeter. These were superseded by the superb gratings of Rowland with something over one hundred thousand lines, and with a resolving power of 150,000.[1]

The theoretical resolving power of a grating is given as was first shown by Lord Rayleigh by the formula $R = mn$, in which n is the total number of lines, and m the order of the spectrum. An equivalent expression is furnished by

$$R = \frac{l}{\lambda}(\sin i + \sin \theta),$$

[1] The 6½ in. gratings now ruled on the Rowland engine have a much higher resolving power—probably 400,000.

where l is the total length of the ruled surface, λ the wave-length of the light, i the angle of incidence and θ the angle of diffraction, and the maximum resolving power which a grating can have is that corresponding to i and θ each equal to 90° which gives $R = 2l/\lambda$; that is twice the number of light waves in the entire length of the ruled surface.

This shows that neither the closeness of the rulings nor the total number determine this theoretical limit, and emphasizes the importance of a large ruled space.

This theoretical limit can be reached, however, only on the condition of an extraordinary degree of accuracy in the spacing of the lines. Several methods for securing this degree of accuracy have been attempted but none has proved as effective as the screw. This must be of uniform pitch throughout and the periodic errors must be extremely small.

For a short screw, for example one sufficient for a grating two inches in length, the problem is not very difficult, but as the length of the screw increases the difficulty increases in much more rapid proportion. It was solved by Rowland in something over two years.

Since this time many problems have arisen which demand a higher resolving power than even these gratings could furnish. Among these is the resolution of doubles and groups of lines whose complexity was unsuspected until revealed by the interferometer and amply verified by subsequent observations by the echelon and other methods.

Others that may be mentioned in this connection are the study of the distribution of intensities within the spectral "lines"; their broadening and displacement with temperature and pressure; the effect of magnetic and electric fields, and the measurement of motions in the line of sight, as revealed by corresponding displacement of the spectral lines in consequence of the Doppler effect.

All of these have been attacked with considerable success by observations with the echelon, the interferometer and the plane-parallel plate. These methods have a very high resolving power, but labor under the serious disadvantage that adjacent succeeding

spectra overlap, making it difficult to interpret the results with certainty.

Some twelve years ago the construction of a ruling engine was undertaken with the hope of ruling gratings of fourteen inches—for which a screw of something over twenty inches is necessary. This screw was cut in a specially corrected lathe so that the original errors were not very large, and these were reduced by long attrition with very fine material until it was judged that the residual errors were sufficiently small to be automatically corrected during the process of ruling.

The principal claim to novelty of treatment of the problem lies in the application of interference method to the measurement and correction of these residual errors.

For this purpose one of the interferometer mirrors is fixed to the grating carriage, while a standard, consisting of two mirrors at a fixed distance apart, is attached to an auxiliary carriage. When the adjustment is correct for the front surface of the standard, interference fringes appear. The grating carriage is now moved through the length of the standard (one tenth of a millimeter if the periodic error is to be investigated; ten or more millimeters if the error of run is to be determined) when the interference fringes appear on the rear surface. This operation is repeated, the difference from exact coincidence of the central (achromatic) fringe with a fiducial mark being measured at each step in tenths of a fringe (twentieths of a light-wave). As a whole fringe corresponds to one hundred thousandth of an inch, the measurement is correct to within a millionth of an inch.

The corresponding correction for periodic errors is transferred to the worm-wheel which turns the screw; and for errors of run to the nut which moves the carriage. In this way the final errors have been almost completely eliminated and the resulting gratings have very nearly realized their theoretical efficiency.

A number of minor points may be mentioned which have contributed to the success of the undertaking.

(*a*) The ways which guide the grating carriage as well as those which control the motion of the ruling diamond must be very

true; and these were straightened by application of an auto-collimating device which made the deviation from a straight line less than a second of arc.

(*b*) The friction of the grating carriage on the ways was diminished to about one tenth of that due to the weight (which may amount to twenty to forty pounds) by floating on mercury.

(*c*) The longitudinal motion of the screw was prevented by allowing its spherically rounded end to rest against an optically plane surface of diamond which could be adjusted normal to the axis of the screw.

(*d*) The screw was turned by a worm wheel (instead of pawl and ratchet) which permits a simple and effective correction of the periodic errors of the screw throughout its whole length.

(*e*) A correcting device which eliminates periodic errors of higher orders.

(*f*) It may be added that the nut which actuates the carriage had bearing surfaces of soft metal (tin) instead of wood, as in preceding machines. It was not found necessary to unclamp the nut in bringing it back to the starting point.

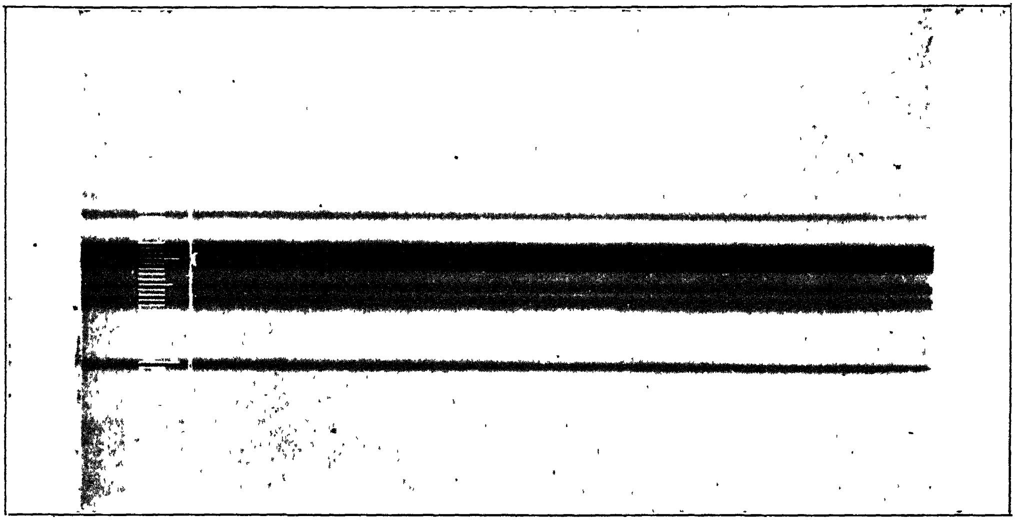
Finally it may be noted that instead of attempting to eliminate the errors of the screw by long continued grinding—which inevitably leads to a rounding of the threads—it has been the main object to make these errors conveniently small; but especially to make them constant—for on this constancy depends the possibility of automatic correction.

The accompanying photograph made with a ten-inch grating, 6th order (actual ruled surface 9.4 inches by 2.8 inches), used in the Littrow form with an excellent 8-inch lens by Brashear, is given in evidence of its performance. The resolving power as shown by the accompanying scale of Angström units is about 450,000. The original negative shows a resolving power of about 600,000. The theoretical value is 660,000.

Doubtless the possibility of ruling a perfect grating by means of the light waves of a homogeneous source has occurred to many—and indeed this was one of the methods first attempted.

It may still prove entirely feasible—and is still held in reserve if

serious difficulty is encountered in an attempt now in progress to produce gratings of twenty inches or more. Such a method may be made partly or perhaps completely automatic, and would be independent of screws or other instrumental appliances.



ENLARGEMENT OF PHOTOGRAPH OF THE GREEN MERCURY LINE λ 5461, taken by H. L. Lemon with 10-inch diffraction grating in sixth order. Scale: 1 division = 0.01 A.U.; ruled surface 9⅜ in. × 2⅞ in., 11,700 lines per inch. Mounted in Littrow form with 8-inch lens by Brashear. Focal length 20 feet.

It may be pointed out that an even simpler and more direct application of light-waves from a homogeneous source is theoretically possible and perhaps experimentally realizable.

If a point source of such radiations send its light-waves to a collimating lens and the resulting plane waves are reflected at normal incidence from a plane surface, stationary waves will be set up as in the Lippman plates; these will impress an inclined photographic plate with parallel lines as in the experiment of Wiener; and the only limit to the resolving power of the resulting grating is that which depends on the degree of homogeneity of the light used. As some of the constituents of the radiations of mercury have been shown to be capable of interfering with difference of path of over

a million waves, such as grating would have a resolving power exceeding a million.

This investigation has had assistance from the Bache Fund of the National Academy of Science, from the Carnegie Institution, and from the University of Chicago.

In addition to the grateful acknowledgment to these institutions I would add my high appreciation of the faithful services rendered by Messrs. Julius Pearson and Fred Pearson.

THE CONSTITUTION OF THE HEREDITARY MATERIAL.

By T. H. MORGAN.

(*Read April 23, 1915.*)

There are two ways in which the relation of the egg to the characters of the individual that develops from the egg has been interpreted.

1. The egg has been thought of as a whole and the characters of the individual as the product of its activity as a unit.

2. The egg has been thought of as made up of representative particles of some sort that stand in a definite relation to the parts of the individual that comes from the egg.

Weismann, whose speculations occupied the forefront of interest at the close of the last century, adopted the latter view; namely, that the germ is made up of particles, which he called determiners. For Weismann embryonic development became merely the sorting out of the particles of the germ to their respective parts of the embryo. Each region of the body owed its peculiarities to the particles that came to it by this sorting-out process. In fact, one may go so far, I think, as to say that Weismann borrowed from Roux this particular form of the preformation in order to give a formal explanation of *embryonic differentiation*. But Weismann's theory soon encountered three serious reverses.

In the first place, the study of the minute structure and behavior of the segmenting egg shows no evidence that any such sorting-out process takes place, as Weismann postulated. It has been shown that the chromosomes divide equally at every division, and that every cell of the body contains the entire complex that was present in the fertilized egg-cell itself.

In the second place, it was shown that the sequence of the cleavage planes of the egg could be artificially altered, yet a normal embryo develop.

In the third place, it was shown that in some eggs each of the first two, or first four cells derived from the egg is capable of forming a whole embryo. This result creates a strong presumption against the adequacy of Weismann's interpretation of development.

Meanwhile one of the greatest biological discoveries of the last century—one that had a very direct bearing on the traditional interpretations of predetermination—was forgotten. I refer to Mendel's work. Mendel showed that when two related organisms, differing from each other in a single character, are crossed, and their offspring are again bred together, that in the second generation individuals appear that are like their grandparents. He showed that the numerical proportions, in which they appear, could be explained on the assumption of one factor difference between the original forms. This result might be interpreted to mean either that the two original germ cells, taken as a whole, represent such a factor difference; or it might be interpreted to mean that the original germ cells had one particulate difference. But Mendel went further, and showed that when two related organisms that differ in two, or three, or more different characters are bred to each other, all possible combinations of the original characters appear later. It might seem then that we must abandon the view that each germ cell is to be thought of as a whole, for we see that the parts of each can be separated to become parts of others. In this sense Mendel's results seem to furnish a brilliant confirmation of Weismann's theory, in so far as it relates to preformation in the germ, and in the last edition of his "Vorträge ueber Descendenz Theorie," Weismann put in his claim to this verification.

In fact, Mendel's discovery does furnish a strong argument in favor of that part of Weismann's view that deals with the constitution of the germ-plasm, but it by no means confirms that part of Weismann's theory which postulates that embryonic development is a sorting-out process of representative particles.

Let us turn our attention, then, to Mendel's law and examine in how far it justifies an assumption that there are specific substances in the germ cells.

Mendel's law postulates that the early germ cells (and it may be added all of the body cells too) contain two of each kind of the

hereditary factors,—one derived from each of its parents. Mendel's law postulates further, that, in the ripening of the germ cells, the members of each pair separate (Fig. 1). Each mature germ cell comes to contain but a single element (or factor) of each kind.

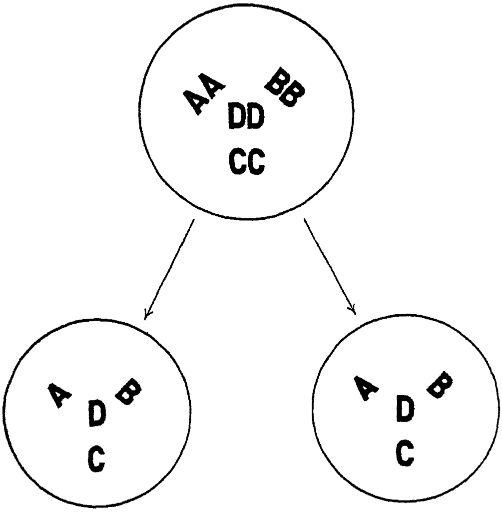


FIG. 1. Diagram to illustrate segregation of factors. The four pairs of factors represented in the upper circle by AA, BB, CC, DD, undergo segregation so that each germ cell comes to contain one member of each pair.

Now students of cytology had quite independently come to this same conclusion in regard to the germ cells. They had found that each cell contains a definite number of chromosomes, and that there are two of each kind of chromosomes in every cell,—one from each parent (Fig. 2, *a*). It had been found that at the ripening of the germ cells the members of each pair of chromosomes conjugate (Fig. 2, *b*), and then separate from each other (Fig. 2, *c*), so that each mature germ cell comes to contain but a single set of chromosomes (Fig. 2, *d*). Furthermore, students of experimental embryology had obtained independent evidence pointing to the chromosomes as the bearers of the hereditary materials.

We find, then, that cytologists had discovered a mechanism in the cell that they had reason to think was the bearer of the hereditary materials, and that the mechanism fulfills the essential

requirements of Mendel's postulates. There were two further steps necessary to bring the two lines of inquiry into complete accord; namely, (1) correspondence between the number of the chromosomes and the groups of inherited characters, and (2) the interchange between the members of the same pair of chromosome.

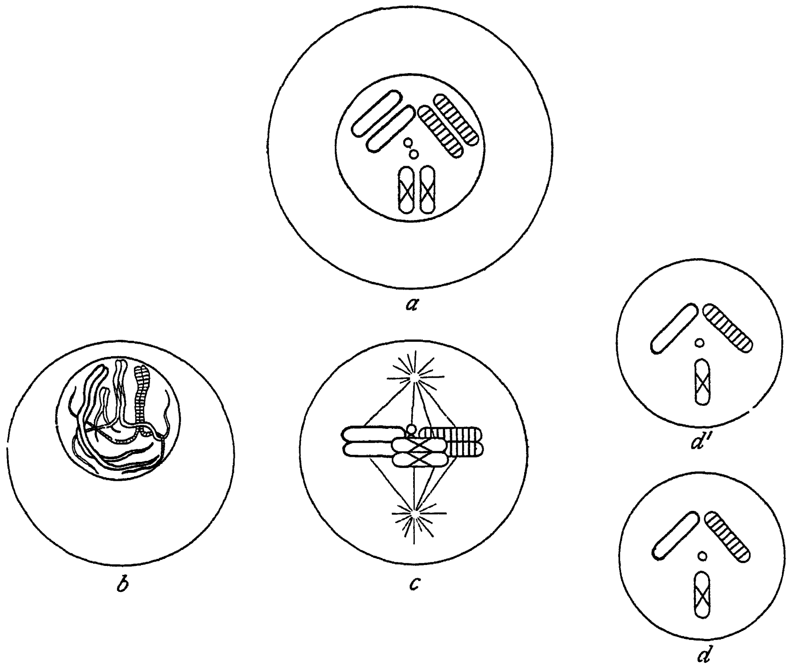


FIG. 2. Diagram to illustrate segregation of chromosomes. The four pairs of chromosomes in the upper circle (*a*), conjugate in (*b*) (synopsis stage), prepare for separation in (*c*) and undergo segregation so that each germ cell (d, d′) comes to contain one member of each pair.

The number of chromosomes is small in comparison with the large number of different characters that an animal or a plant possesses. We should expect therefore if in any animal or plant a sufficient number of character-differences were known that the characters would be found to be inherited in groups, and that the number of such groups should be the number of chromosome pairs that such an animal or plant possesses. In very few cases have enough characters been found to make such a comparison of any value.

But in the fruit fly, *Drosophila,* that has been intensively studied for five years, over a hundred new, and inherited characters have appeared. They fall into four great groups. A partial list of the four groups is as follows:

GROUP I.

Name.	Region Affected.
Abnormal	Abdomen
Bar	Eye
Bifid	Venation
Bow	Wing
Cherry	Eye color
Chrome	Body color
Cleft	Venation
Club	Wing
Depressed	Wing
Dotted	Thorax
Eosin	Eye color
Facet	Ommatidia
Forked	Spines
Furrowed	Eye
Fused	Venation
Green	Body color
Jaunty	Wing
Lemon	Body color
Lethals, 13	Die
Miniature	Wing
Notch	Venation
Reduplicated	Eye color
Ruby	Legs
Rudimentary	Wings
Sable	Body color
Shifted	Venation
Short	Wing
Skee	Wing
Spoon	Wing
Spot	Body color
Tan	Antenna
Truncate	Wing
Vermilion	Eye color
White	Eye color
Yellow	Body color

GROUP II.

Name.	Region Affected.
Antlered	Wing
Apterous	Wing
Arc	Wing
Balloon	Venation
Black	Body color
Blistered	Wing
Comma	Thorax mark
Confluent	Venation
Cream II	Eye color
Curved	Wing
Dachs	Legs
Extra vein.	Venation
Fringed	Wing
Jaunty	Wing
Limited	Abdominal band
Little crossover	II chromosome
Morula	Ommatidia
Olive	Body color
Plexus	Venation
Purple	Eye color
Speck	Thorax mark
Strap	Wing
Streak	Pattern
Trefoil	Pattern
Truncate	Wing
Vestigial	Wing

GROUP III.

Name.	Region Affected.
Band	Pattern
Beaded	Wing
Cream III	Eye color
Deformed	Eye
Dwarf	Size of body
Ebony	Body color
Giant	Size of body
Kidney	Eye
Low crossingover	III chromosome
Maroon	Eye color
Peach	Eye color

GROUP IV.

Name	Region Affected.
Bent	Wing
Eyeless	Eye

GROUP III.—*Continued.*

Name.	Region Affected.
Pink	Eye color
Rough	Eye
Safranin	Eye color
Sepia	Eye color
Sooty	Body color
Spineless	Spines
Spread	Wing
Trident	Pattern
Truncate intensf.	Wing
Whitehead	Pattern
White ocelli	Simple eye

The four pairs of chromosomes of *Drosophila* are shown in the next diagram, Fig. 3.

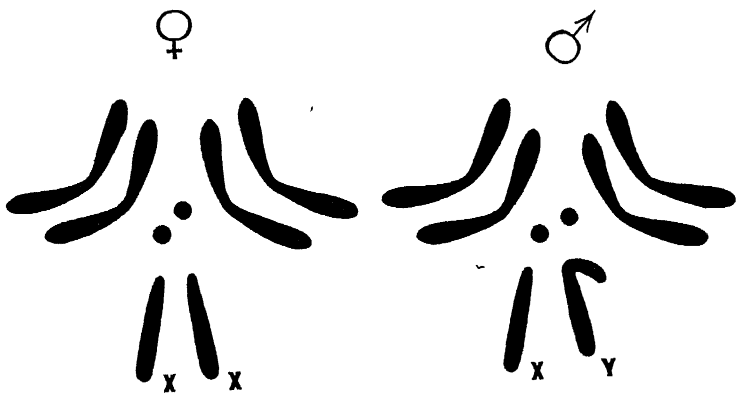


FIG. 3. Diagram of the four pairs of chromosomes of Drosophila ampelophila; to the left the chromosomes of the female; to the right those of the male.

The correspondence between the four character groups and the four pairs of chromosomes is obvious even to the size relations. This relation, or correspondence, does not however tell us anything in respect to the way in which the chromosomes stand for the characters of the group. So far, the result only shows that the characters of a given group are in some way represented in a particular chromosome. Our work has, however, carried us beyond this point. I may illustrate this by an example from the first group, containing sex linked characters. We mean by sex linked characters that they follow the known distribution of the X chromosomes. For in-

stance, the factor that determines the character for white eyes is sex linked, as is also the factor that determines the character for miniature wings. If we cross a female with white eyes and miniature wings to a male with red eyes and long wings, the sons will have white eyes and miniature wings. The explanation of this result is found in the distribution of the chromosomes. The sons get their single X chromosomes from their mother. Hence they show the characters that this chromosome carried in the mother, who had white eyes and miniature wings. The daughters, however, get one of their X chromosomes from their father through his female producing sperm. This chromosome carried a factor for red eyes and another for long wings, which factors dominate those carried by the other X chromosome that the daughters get from their mother, namely, the factors for white eyes and for miniature wings. These relations are shown in Fig. 4.

If these daughters and sons are bred to each other they produce four kinds of individuals, viz., red long, white miniature, red miniature, and white long. These are the four classes that Mendel's law calls for, but they do not occur in the Mendelian proportion (9:3::3:1) when two pairs of factors, as here, are involved. The reason for this is two-fold. In the first place the female alone carries two X chromosomes. The male carries but one. Hence there is an unequal distribution of the X chromosomes in the spermatozoa, for, only half of them can get an X chromosome. These are the female-producing spermatozoa. The result is, as has been shown, that in the first generation the sons inherit their single X chromosome from their mother and none of the dominant characters of the father. Since in this case the sons carry no dominant factor either in their X bearing (female producing), or in their Y bearing (male producing sperm), the second generation here reveals completely the composition of the egg cells that the F_1 female carries.

On Mendel's law of random assortment of two pairs of factors we should expect the four classes that here appear in the second generation to be equal in number. On the contrary we find that two of them are twice as numerous as the other two. On inspection we see that the two larger classes are white miniature and red

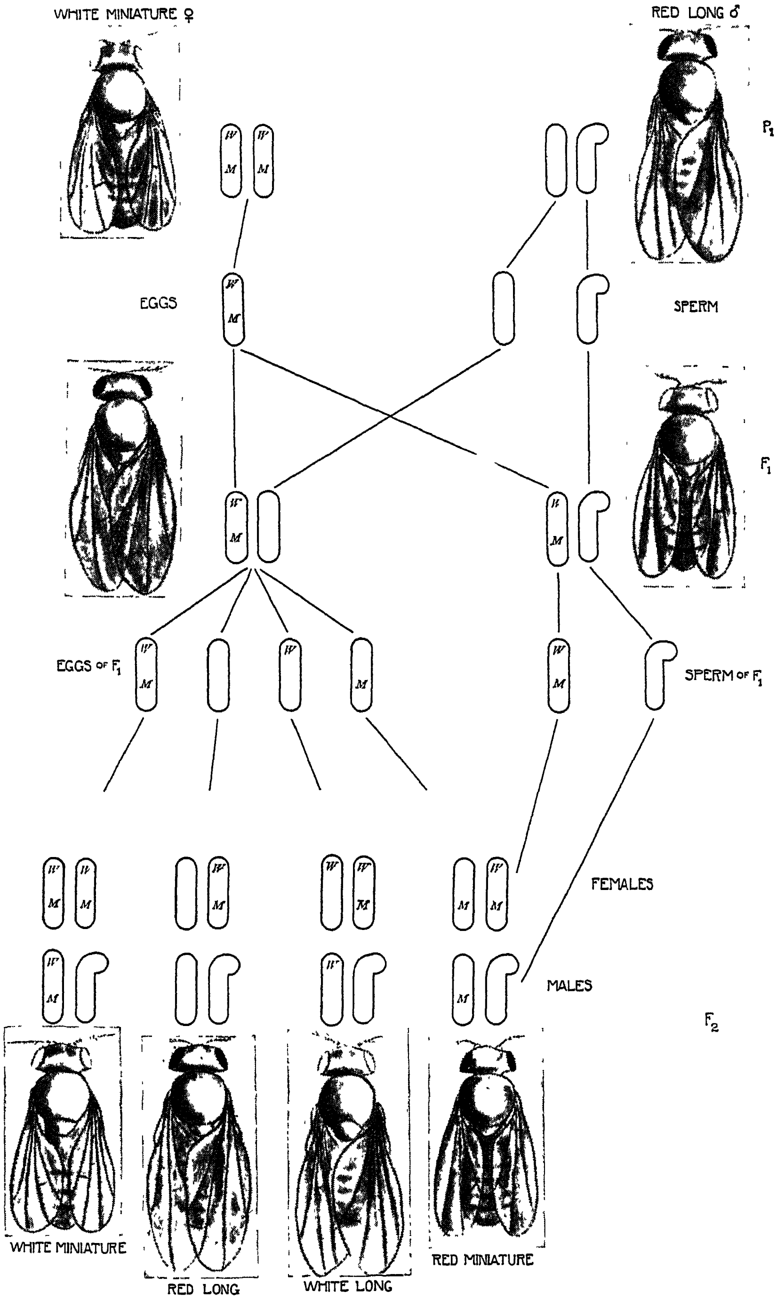


FIG. 4. Diagram to show the inheritance of two pairs of recessive sex linked characters, viz. white eyes (W) and miniature wings (M). The normal, dominant allelomorphs of these factors are omitted.

long. These correspond to the two grandparents. The two smaller classes are white long and red miniature.

We can account for this result if we assume first that the two factors that went in together in the same chromosome tend to hold together. This would account for the two larger classes. Second that the two smaller classes are due to interchanges between the two X chromosomes. Such interchange would here take place only once in three times.

We can test this conclusion by planning the experiment in such a way that white and miniature now go in from opposite sides,—white from one parent, and miniature from the other. When we do this we find that the large classes in the second (back cross) generation will be red miniature and white long and that the small classes will now be red long and white miniature. The ratio of the large to the small classes will be exactly the same as in the first case. In other words the interchange between the X chromosomes is the same regardless of what factors each contains.

If one admits that the chromosomes are the bearers of the hereditary factors he is forced to admit that experiments like these prove that somehow interchange of factors in homologous chromosomes must occur.

If one thinks of the factors as lying in a linear series in the chromosome (and there is certain evidence that I can not consider here that makes this view imperative) then the chance of a crossing over taking place somewhere in the region between two pairs of factors would be greater the farther apart the factors lie. The percentage of times that crossing over takes place becomes then a measure of the distance apart of the factors in question. If we make this assumption we find that we can give a consistent explanation of everything that we have found in the inheritance of linked factors in *Drosophila*. Not only this, but a far more important fact comes to light. If we determine, on the aforesaid basis, the relation to each other of all the known factors in each of the four groups, then, when a new factor appears, we need only determine its group and its relation to two factors in that group. With this information we can predict its relation to all other members of that group. In other words we can predict what the numerical relation

will be in the second generation. There is no other way as yet discovered by means of which this relation can be predicted.

If we compare our conception of the structure of the germ plasm with that of Weismann we find in all of his writings except the last one, that he supposed the chromosomes to be alike and that each consisted of a series of ids that contained the totality of the determiners that influence development.

It is true that in his last writing he partially abandons his earlier idea of *whole ids* for a conception nearer to ours of *partial ids*,—at least for some of the determiners. In this respect his view more nearly approaches the one here maintained. But even then his view not being based on numerical data would leave us entirely helpless in explaining the phenomena of inheritance in any particular case. Without wishing in the least to detract from the value of Weismann's brilliant speculation, nevertheless the difference in the way in which the conclusions were reached in the two cases is one of fundamental significance in all scientific work. Our view is based on accurate numerical data that enables us to predict what any given result in this field will be. It is this power to predict that gives significance to a scientific theory. In this regard we believe that our interpretation is a long step in advance of the purely imaginative conception of the germ plasm that Weismann advanced.

If now we bring our conception of the germ plasm to bear on the problem of development we have a very different view point of that process from the one Weismann pictured.

We think of every cell in the body containing one set of chromosomes received from the mother plus one set from the father. The materials carried by these chromosomes influence development in their entirety. Although we are able to localize certain materials in the chromosomes that when present cause the eyes to be white, and others that cause the eyes to be red, we do not mean that these materials in the chromosomes go directly only to the parts that show their influence more markedly. We mean that given one kind of material and the rest of the cell there is elaborated a white eye; given a different material in the same locus it produces, in conjunction with the rest of the cell, a red eye.

To say that the germinal material that makes a white eye is different from the germinal material that makes a red eye is a platitude. But to be able to locate a particular material in the one case *in relation to other materials* is a very different matter, because by means of this information we are able to explain the results on a mechanistic basis, and are able to predict the results of untried combinations. Without this information the prediction would be impossible.

We are led then to a third conception of predetermination. It is this! That while the hereditary material is made up of different discrete and separable particles (chemical substances) that have a definite position in the chromosomes, the effects of each of these particles must be supposed to be produced in combination with many, or even with all other parts of the cells in which they are contained.

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New York.

SPONTANEOUS GENERATION OF HEAT IN RECENTLY HARDENED STEEL.

By CHARLES F. BRUSH.

(*Read April 22, 1915.*)

Two or three years ago, when studying the behavior, under certain conditions, of several specimens of hardened tool steel, I observed that they all spontaneously generated a small quantity of heat, the amount of which diminished from day to day, but which was observable for several weeks. In each case the steel had been hardened only a few days prior to its use. It seemed highly probable that the generation of heat was associated with some sort of "seasoning" or incipient annealing process, perhaps accompanied by slight change of volume, and that it would be most rapid immediately after hardening. I resolved to investigate this curious phenomenon more fully, but failed to spare the time until a few months ago. This investigation forms the subject of the present paper.

Fig. 1 is a diagram of the apparatus employed. *A*, *B* represent two large silvered Dewar vacuum jars selected to have very nearly equal thermal insulating efficiency. They are supported in a wooden rack inside a thick copper cylinder *C* packed in granulated cork in a wooden box *E*. *D* is a paper extension of *C*, packed with layers of felt by removal of which and the loose copper cover of *C* easy access is had to the Dewar jars. The copper cylinder weighs 52 pounds and its functions are, by reason of its large thermal capacity and high conductivity, to protect the Dewar jars from any rapid change of temperature, and from temperature stratification.

The box *E* is surrounded by a much larger wooden box *F* lagged with a half-inch layer of felt. A long resistance wire is strung back and forth in the air space between the boxes at the bottom and four sides of *E*. Electric current controlled by a thermostat warms the wire, whereby the temperature of the air space may be maintained very nearly constant as many days or weeks as desired. A

thermometer T, easily read to hundredths of a degree, indicates the temperature of the air space.

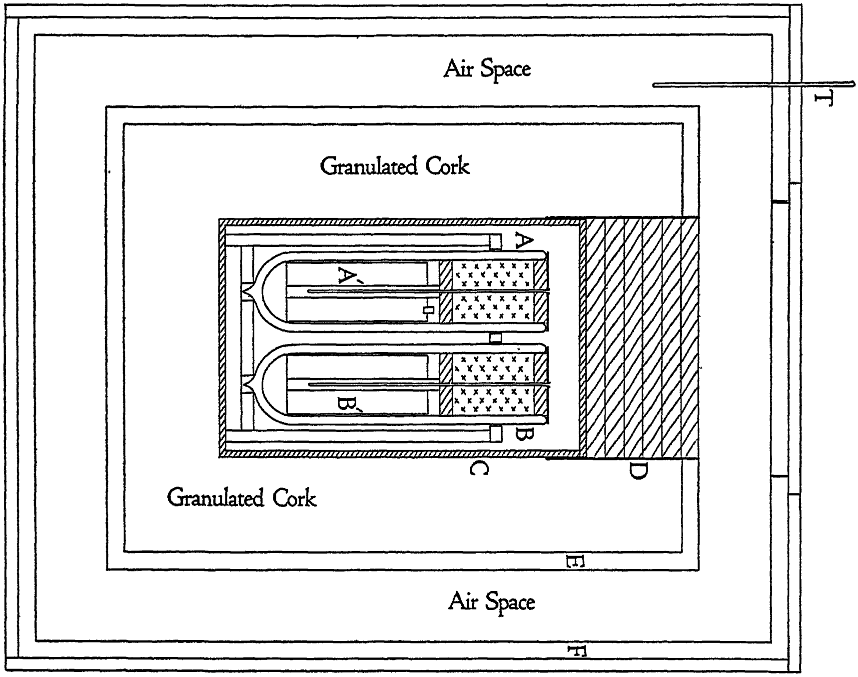


FIG. 1.

Returning now the core of the apparatus: A' is an air-tight cylinder of thin copper, six inches high and two and a half inches in diameter, provided with an open half-inch axial tube also of copper. A small round opening at the top of A' permits the introduction of a weighed quantity of water, after which the opening is tightly corked to prevent any change of temperature by evaporation of the water. B' is another copper cylinder just like A' except that it has a removable top to permit the introduction of the substance whose thermal behavior is to be investigated. The high thermal conductivity of these copper cylinders prevents temperature stratification within them. The Dewar jars are filled above the copper cylinders with layers of felt, and granulated cork, and covered with waxed cardboard carefully sealed on to prevent temperature dif-

ference inside the jars which would follow unequal loss or gain of moisture by the felt and granulated cork. A small thin glass tube, flanged at top and closed at bottom, is located in the axis of each Dewar jar and extends from the waxed cover nearly to the bottom of the inclosed copper cylinder. The glass tubes contain the ends of thermo-electric couples of fine constantan, copper and iron wires, one iron-constantan and one copper-constantan junction at the bottom of each tube. The leading-out wires are copper, and connect the thermo-couples with a reflecting galvanometer having the customary reading telescope and scale. Careful callibration has shown that 55 scale divisions of the galvanometer indicate one degree C. temperature-difference between A' and B', and that temperature-difference and galvanometer deflection are very closely proportional throughout the range used.

In the following experiment A' and B' were removed from the Dewar jars and allowed to attain equal room temperature. Twelve half-inch round bars of tool steel, five inches long and with machined surfaces, were hardened by heating to high "cherry-red" in a reducing atmosphere of a gas furnace and quenching in *cold* water. The bars then had a thin and strongly adhering coating of black oxide. They were next stirred in a large quantity of water at room temperature, to acquire that temperature, wiped dry, and oiled with heavy, neutral mineral oil to prevent generation of heat by further surface oxidation, wiped free of excess of oil and placed in the copper cylinder B'. A weighed quantity of water, also at room temperature, just sufficient to equal the steel bars in thermal capacity had already been placed in A'. The whole apparatus was then assembled as quickly as possible, and galvanometer readings commenced within forty-five minutes of the time of hardening the steel.

The upper curve in Fig. 2 shows the progress of heat generation in the steel bars during the first 150 hours after hardening. A very slow generation of heat was still easily observable at the end of a month.

It is seen that the temperature of the steel bars was rising rapidly when the galvanometer readings commenced, and reached a point (nearly 3° C. at the summit of the curve) where gain and loss of heat balanced each other in about 8 hours.

The "Normal Cooling" curve was obtained five or six weeks after the other, and when the generation of heat had very nearly

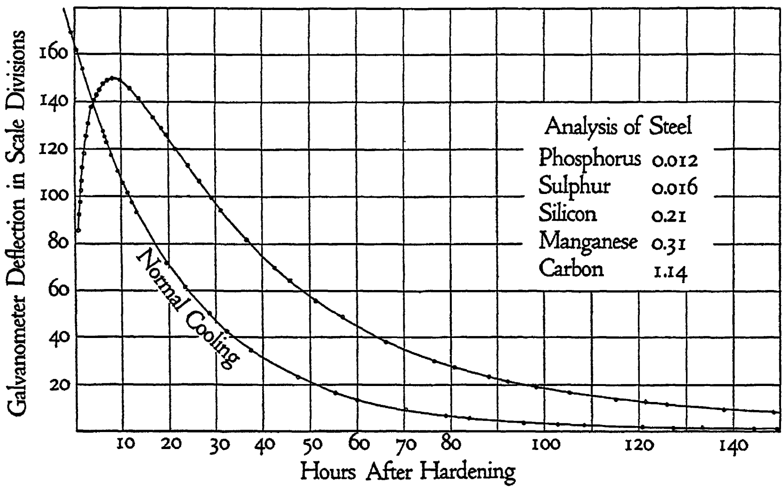


FIG. 2.

ceased. For this purpose the steel bars were removed, warmed a few degrees, and replaced; then galvanometer readings were made from time to time as before. This curve is plotted in a location convenient for visual comparison with the heating curve, but otherwise might just as well be plotted further to the right.

From the two observed curves I have computed a third curve (not shown) which represents the progressive rise in temperature which would have occurred if the thermal insulation of the steel had been perfect, so as to prevent any loss of heat. The curve is strikingly similar in character to the shrinkage curve shown in Fig. 5, and indicates a close association of heat generation and shrinking, to which I shall refer again. The total rise in temperature indicated (about five degrees C.) is of little quantitative importance because it is highly probable that it would have been different if the steel had been hardened at a different temperature, or more uniformly hardened throughout each bar, or had a different carbon content. Yet it is interesting to note that the observed quantity of heat spontaneously generated in the steel, measured by its rise in temperature multiplied by its thermal capacity, indicates internal

work of some sort sufficient to lift the steel bodily about 800 feet high against the force of gravity.

I next prepared a batch of "high-speed" tungsten steel consisting of the same number of bars of the same dimensions as in the first experiment. The bars were water-hardened at white heat, not far below the fusing point, brought to room temperature, oiled and introduced just as in the former case, and galvanometer readings were commenced an hour after hardening.

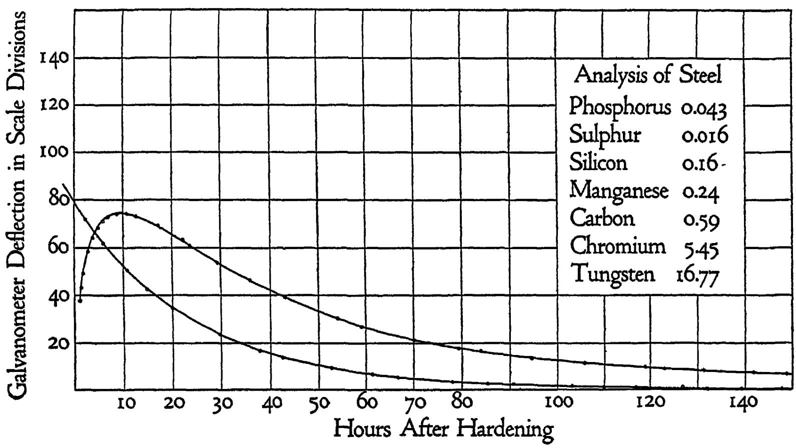


FIG. 3.

Fig. 3 shows the curve of heat generation in the "high-speed" steel, and the curve of normal cooling located with respect thereto as in Fig. 2. The cooling curve here shown is the lower part of that used in Fig. 2. It is permissible to use the same cooling curve for both kinds of steel because the thermal capacity of the two lots was very nearly the same.

It is seen that heat generation in the tungsten steel was the same in character as in the carbon steel of Fig. 2, though much less in amount and somewhat more persistent.

Many workers in steel are aware that the metal expands a little when hardened, and shrinks when annealed; but I have not met with any quantitative data on the subject. With the hope of throwing some light on the spontaneous generation of heat already described, I investigated this phenomenon of swelling and shrinking as follows:

Having no more of the carbon steel used in the first experiment, I procured another half-inch round bar of the same brand, though slightly different in composition as the analyses show. With a piece of this bar two and a half inches long I made a careful determination of its specific gravity under the conditions, and with the results, shown in the following table.

TABLE I.

Specific Gravity		Analysis of Steel	
Commercial Condition	7.8507	Phosphorus	0.015
After Hardening	7.8127	Sulphur	0.021
After Tempering to Light Blue	7.8350	Silicon	0.16
After Annealing	7.8529	Manganese	0.33
		Carbon	1.07

The difference in density and volume between the hardened and annealed conditions is fully a half per cent., which is much more than I expected to find; and nearly half of the total shrinkage was brought about by the very moderate heating necessary for "tempering to light blue." The annealing was very thorough, and, as the figures show, was more complete than in the annealed "commercial condition."

The shrinkage incident to tempering was large enought to encourage the hope that if any spontaneous shrinking, at room temperature, occurs during the generation of heat which follows hardening, it might be detected and measured. For this purpose the apparatus shown in Fig. 4 was designed and constructed.

In Fig. 4 *G* and *H* are two vertical steel rods three feet long and one millimeter in diameter. They are hung from a common rigid metal support *I*, and at their lower ends carry parallel brass bars *G'*, *H'* which move with perfect freedom, yet in close contact, between guides *K*, *K*. The brass bars are accurately machined, and their front edges are polished. The rod *G*, whose function is purely comparative, is kept under moderate and constant tension by the long spiral spring *L*; while the rod *H* carries a four pound weight *M*. An enlarged sectional diagram at the right shows the method employed in mounting each steel rod. Each end of the rod passes through, and is soldered into, a brass head having a hemi-

spherical end which accurately seats itself in a hollow metal cone. The rods are quickly removable through vertical slots in the cones.

After some preliminary experiments, to get acquainted with the apparatus, a fresh rod *H* was hardened by placing it horizontally in a wooden rack just above a trough of water at room temperature, quickly heating it to bright redness by passing suitable electric

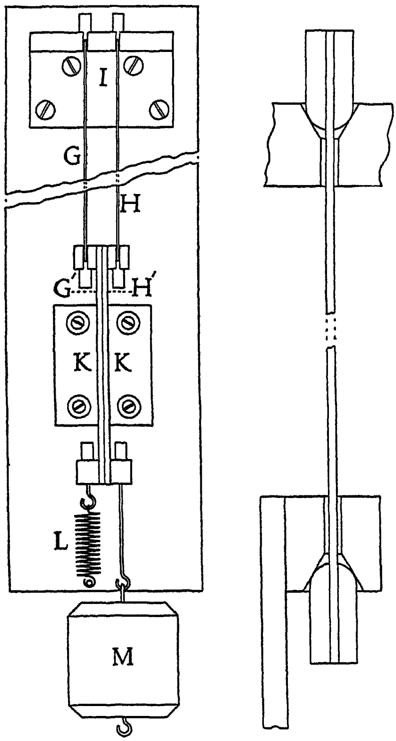


FIG. 4.

current through it and plunging it in the water beneath, the act of lowering the rod serving to break the electric circuit. The rod was kept straight while hot by means of a weak spiral spring which took up the expansion. Preliminary experiments had shown that a rod could be hardened in this way without warping.

The hardened rod, already at room temperature, was quickly wiped dry and put in place beside *G*. Then, without delay, a fine

horizontal scratch was drawn across the polished fronts of the bars *G′*, *H′* by means of a straight-edge and sharp needle point lightly applied. A microscope, magnifying about 200 diameters and very solidly mounted, was brought into position and focused on the horizontal scratch, which of course consisted of an independent scratch on each bar, the two halves being initially in perfect register. The microscope was provided with a filar micrometer eyepiece carefully calibrated and adapted to measure accurately any departure from register of the two half lines or scratches.

Shrinkage of the hardened rod *H* was detected within two minutes after scratching the brass bars, and was easily observable at the end of two weeks.

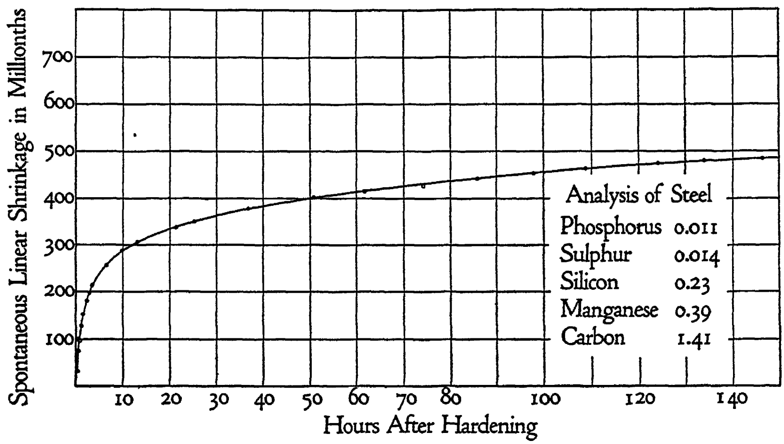


Fig. 5.

Fig. 5 shows the progress of shrinking during the first 150 hours. The curve reached the 500 line a day or two later. The hardened length of the rod was assumed to be 35 inches, so that its actual shrinkage at the 500 line of the curve was 0.0175 inch.

The rod was next scoured clean and tempered to light straw color by electric warming, then to light blue color, and its total shrinkage measured after each operation. Finally, it was thoroughly annealed by bedding in mineral wool, heating to very low redness half an hour, and then gradually reducing the heating current to nothing in the course of two or three hours, after which

the shrinkage was again measured. The rod shrank very considerably in each operation, as indicated quantitatively in Table 2, in which the annealed length is taken as unity or 100 per cent.

TABLE 2.

Length of rod after hardening	100.383
After spontaneous shrinking	100.332
After tempering to light straw	100.182
After tempering to light blue	100.131
After annealing	100.000

Of course the shrinkage in volume must have been very nearly three times the linear shrinkage, or considerably more than one per cent. from the hardened to the annealed condition, which is more than double that observed in the bar steel used in the first experiment. Doubtless this was due to the higher carbon content of the small rod, and more uniform hardening owing to its small size. It is highly probable also that more heat was generated per unit of mass.

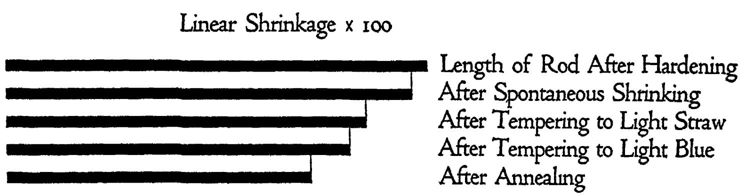


FIG. 6.

In Fig. 6 I have visualized the stages of shrinking of the small rod by magnifying a hundred-fold the observed quantities in Table 2.

I have already pointed out the close similarity in character of the spontaneous-shrinkage curve (Fig. 5) and the computed curve of total heat generation; and there seems little room for doubt that the two phenomena are quantitatively related. But it is equally clear that spontaneous shrinking is only incident to, and is not the prime cause of the generation of heat, because the internal work represented by the heat generated is hundreds of times more than necessary to bring about the accompanying change in volume. This

is found as follows: The small steel rod spontaneously shrank 0.0175 inch. To spring it back to its original length required a weight of 15 pounds hung below *M*, Fig. 4 (= 12.400 pounds strain per square inch of cross-section). Hence, in longitudinally shrinking 0.0175 inch, the rod had done work equal to lifting 15 pounds half this distance or 0.00875 inch. The rod weighed about 1230 times less than the weight, so that the work done was sufficient to lift the rod itself $1230 \times .00875 = 10.76$ inches. But this represents one-dimensional shrinking only, and we must take three times this amount of lift, or, say 2⅔ feet, to represent the work done in the three-dimensional shrinking which certainly occurred. We have already seen that the internal work spontaneously done in the steel bars of the first experiment, in generating the observed amount of heat, was sufficient to lift the bars about 800 feet, which is 300 times greater than the work done in spontaneously shrinking the small rod. If spontaneous shrinkage was less in the large bars than in the small rod, which is highly probable, then this ratio was accordingly greater than three hundred to one. The disparity in weight between the twelve large bars and the one small rod does not count, because the work done in each case is computed for the weight of steel which did it.

It has been suggested that loss of the generated heat may perhaps be regarded as a cooling process without change of temperature (which implies reduction in specific heat), and that this may be sufficient to account for the spontaneous shrinkage. But this hypothesis accounts for only a modest fraction of the shrinkage; while the implied change in specific heat is much too large to be admissible.

An attempt was made to measure Young's modulus of elasticity in the small rod both in the hardened condition (after spontaneous shrinking) and after annealing, by hanging various weights below *M*, Fig. 4, and measuring with the microscope the distortions produced,—always far within the elastic limit. But I was unable to obtain reliable results because of an interesting fact which was brought to light, as follows: In the annealed condition the steel exhibited a small amount of viscosity or internal friction which somewhat delayed full distortion and subsequent restitution; but in the

hardened condition the viscosity was *many times greater*. This is a further illustration of the instability of the hardened steel.

In conclusion, I am led to regard the hardened steel as being in a condition of very great molecular strain somewhat unstable, especially at first. Spontaneous relief of a small portion of the strain causes generation of heat until stability at room temperature is reached. Any considerable rise of temperature, as in tempering, permits further spontaneous relief of strain, or molecular rearrangement, doubtless accompanied by more generation of heat, and so on until annealing temperature is reached. It is obvious that the process of tempering or annealing steel is an exothermic one, and conversely that hardening is an endothermic process.

CLEVELAND,
April, 1915.

RELATIONSHIPS OF THE WHITE OAKS OF EASTERN NORTH AMERICA,

WITH AN INTRODUCTORY SKETCH OF THEIR PHYLOGENETIC HISTORY.[1]

BY MARGARET V. COBB.

(PLATES IV–VI.)

(Read April 23, 1915.)

I. HISTORY OF THE FAGACEÆ: A RECONSTRUCTION.

Prantl's Classification of the Fagaceæ.

Castaneæ	Quercus. Pasania. Castanea.
Fageæ	Fagus. Nothofagus.

The five or six genera of the family Fagaceæ to which the oaks belong were well differentiated at least as far back as the Cretaceous age. The beeches are sharply separated from the remainder of the family (the pasanias, chestnuts and oaks), and are undoubtedly the more primitive of the two groups. *Nothofagus,* the genus of primitive beeches, is a characteristically sub-Antarctic genus, still surviving in Tasmania, New Zealand, and the southern part of South America (a South Pacific distribution). *Fagus* itself, once more widely spread, is now found only in Japan, North America and Europe.

The pasanias, chestnuts and oaks are at present in possession of the temperate and tropical regions of Asia, North America, Europe and Mediterranean Africa. Species are most numerous in southeast Asia and in Mexico (regions separated by the Pacific). *Pasania* is limited to southeast Asia, except for one species in California

[1] This paper owes a great deal to the extensive knowledge and the never-failing interest and aid of Dr. William Trelease, under whom the work was done at the University of Illinois in the year 1913–14.

and one in New Zealand (ranges separated by the Pacific). *Castanopsis* (the less specialized chestnuts) is limited to southeast Asia, except for two Californian species (ranges separated by the Pacific). *Castanea* is present in southeast Asia, North America and Europe. *Quercus* has most numerous species in southeast Asia and (especially) Mexico and Central America (regions separated, again, by the Pacific), while the subgenus *Cyclobalanopsis* is limited to southeast Asia (monsoon province). In consideration of the facts that the most primitive genus still lingers on the two sides of the southern Pacific, and that so many other groups are found only in regions bordering on the northern Pacific, it is more than plausible that the family Fagaceæ originated in the Antarctic-Pacific region, and moved northward towards its present northern-hemisphere distribution in the region of the Pacific Ocean. This of course involves the hypothesis of an ancient Cretaceous or pre-Cretaceous Pacific continent—for which there is much other distributional evidence and which Scharff,[2] among others, holds to be highly probable. The broad similarity of the ranges of *Pasania, Castanopsis* and *Cyclobalanopsis* was undoubtedly determined at this early time. The problem of the extension of certain species of *Fagus* and *Castanea* to Europe seems entirely separate, and probably belongs to a more recent period. *Quercus* is involved with both the older and the more modern distribution; they have been mapped out here for convenient reference in the coming discussion of *Quercus*.

II. History of Quercus, Hypothetically Reconstructed.

Oaks, living or fossil, have been reported from every continent. Living species, however, are unknown in the southern hemisphere, except that they are found south of the equator in the East Indies, and among the mountains of Ecuador (localities separated by the Pacific). Species, as was said, are most numerous in Mexico and Central America and in southeast Asia; the subgroup *Cyclobalanopsis* is limited to southeast Asia. Remembering that *Pasania* and *Castanopsis* are almost limited to the same region, and that the pasania-chestnut-oak group of the Fagaceæ shows here a concentration, and a profusion of species, seen nowhere else in the world,

[2] Scharff, "Distribution and Origin of Life in North America."

it is natural to suppose that this part of Asia (or more probably, to allow for the outlying species in California, and the oaks in Mexico, a region *east* from southeast Asia) has been the center of distribution, and hence the point of origin of the pasania-chestnut-oak group. And *Quercus* itself, with its black oaks limited to America, its *Cyclobalanopsis* limited to southeast Asia, and its numerous white oak species in both places, undoubtedly differentiated from the pasanias (or their ancestors) in one or other of these regions, or more probably between the two. At any rate, the primitive, little-differentiated *Quercus* must have had a distribution that included both regions, as well as the space between them. We are thus brought again to an hypothetical Pacific continent; for since neither black oak nor *Cyclobalanopsis* exists or gives evidence of having existed in western Asia or Europe, any cretaceous or earlier connection of the two regions in that direction is well-nigh inconceivable. (It is unnecessary to suppose that this Pacific land extended much farther north than the equator).

According to our hypothesis, the disappearance of this Pacific land isolated the two extremes of the range of *Quercus*. The genus had already become differentiated; the Asiatic part of the range received the stock of *Cyclobalanopsis* (found nowhere else) as well as the more typical *Quercus* stock. Certain species of *Quercus*, even today, form a part of the oldest Asiatic flora, which holds its own in isolated regions,—in parts of the Himalayas, for instance. Some of these ancient endemic species are the white oaks *Q. lanata, semecarpifolia,* and *dilatata,* of which the last is said by Schottky to stand nearest of all oaks to the *Cyclobalanopsis* group. (American black oaks, however, show certain features in common with *Cyclobalanopsis*—apical ovules, type of style).

The American end of the range received a group of oaks of which (according to evidence from distribution and palaeontology) *Quercus chrysolepis* is probably our nearest representative; these may have been the basis of both the black and the white oaks of America. It is suggestive to find that *Q. semecarpifolia* (representative of the ancient oaks of Asia) bears some resemblance to this early American oak. Some of the European oaks are also of this ancient type; but since one, *Q. Ilex,* occurs in both Asia and Europe,

the inference is that they all reached Europe westward from Asia. Though the older fossil evidences in this continent have all been referred to *Q. chrysolepis* (these date back to the Cretaceous), it seems not improbable that types such as *Q. emoryi* and *Q. hypoleuca* were soon present, and that differentiation early took the lines towards our American *black oaks* and *white oaks.* Since in *Cyclobalanopsis,* and in the pasanias, the abortive ovules are carried upward in growth till in the mature acorn they are typically apical, this may be considered the primitive condition in *Quercus.* *Chrysolepis,* which has them only lateral, is on the way towards having them in the basal, white-oak, position. The black oaks, on the contrary, have preserved the primitive character in this as in other particulars.

(Since the black oaks resemble *Cyclobalanopsis* in some ways, it may be that they differentiated from *Cyclobalanopsis,* in the Pacific region, before reaching America. Or all three may have diverged together from the primitive *Quercus.* Distribution may have been such that *Cyclobalanopsis* went to Asia, *Erythrobalanus* to America, *Lepidobalanus* to both.)

Having thus some conception of a possible Cretaceous history for American oaks, black and white, and of their relationship to the ancient types of Old World oaks, we may now limit ourselves to the white oak group in North America (*Leucobalanus*). For the black oaks, being limited to the western hemisphere and becoming only more sharply differentiated, can give us no further light on white oak relationships. To begin with, we may mark off *Leucobalanus* as follows:

QUERCUS.

Cyclobalanopsis: Abortive ovules apical, styles short, subcapitate, often recurved, cup scales grown into a solid ring, fruit ripening in one year, leaves evergreen, tertiary nerves very fine.

Erythrobalanus: Abortive ovules apical, styles elongated, subcapitate, often recurved, acorn tomentose within, cup scales thin, appressed, fruit ripening in two years, leaves deciduous or evergreen, lobes when present with bristle points.

Styles slender or very short and flattened, not cephalated at apex. *Lepidobalanus.*

Cerris: Abortive ovules basal, styles long, tapering, cup scales often long, bractlike, fruit ripening in two years, leaves more or less dentate.

Leucobalanus: Abortive ovules basal, styles very short, spatulate, acorn not tomentose within, cup scales often thickened at base, fruit ripening in one year, leaves deciduous or evergreen, lobes when present rounded.

The most stable characters in this classification seem to be the position of the abortive ovules, the lining of the acorn shell and the form of the style. Appression of scales, time for ripening fruit, and time of keeping leaves are all more or less variable among the white oaks.

The earliest home of *Leucobalanus* on this continent, using the term to include the white oaks as they separated themselves from the black oaks in America, seems to have been northern Mexico and the southwestern states. The older type (A. below) still predominates in this region, which has probably long been stable, with a climate similar to the present. It is a region which seems to have been for many species a center of distribution to other parts of the continent. Since the Cretaceous, much differentiation has taken place, the main lines of which may be represented by the following division of North American white oaks:

A. Leaves persistent, usually evergreen, entire, sinuate or dentate, or, if deeper lobed, with pungent tips.
  1. Many species, southwestern U. S. and Mexico.
  2. *Virginiana* and varieties—an early offshoot.

B. Leaves deciduous, lobed or divided, or serrate; lobes rounded, obtuse or acute but not pungent.

The evergreen series, represented, say, by *Q. undulata,* is the more direct continuation of the Cretaceous type, the deciduous the more modern form.

It is barely possible that not all of this differentiation took place on this continent. *Leucobalanus* reached Europe at some time; and the possibility that this took place early (by means of Scharff's Mediterranean land bridge), and that the deciduous oaks originated there, rather than on this continent, must be taken into account. Species of this type occur also in Asia, but there seems to be little doubt that they are sharply separated from the ancient Asiatic species like *semecarpifolia,* and reached Asia in the Tertiary from the eastward. The fact that the range of these species, in the Ter-

tiary, was, at the boreal end, continuous from Asia across America to Europe, gives the possibility of the center of distribution being either in Europe or in America. My data on European oaks are insufficient to decide this point; it seems, however, highly probable that the white oaks with thin, deciduous, lobed leaves originated in or near northern Mexico.

The early members of the group *Leucobalanus,* then, marked by entire, evergreen leaves, gave rise, probably in North America, to a form with thin, deciduous, lobed leaves. This type is now dominant over the greater part of the United States, while the older form holds its own in the southwest and in Mexico, where the climate has probably known no great fluctuations since the Cretaceous, and where it still finds suitable dry and arid habitats. This evergreen type occupies the Mexican highlands, Arizona and New Mexico, extending east into Arkansas, and west into California. *Quercus virginiana* seems also to have been a very early offshoot; with its varieties it forms a well-marked coastal group, ranging from North Carolina south along the shores of the Gulf into Mexico (where it stretches inland up the mountain sides), and appearing also on the California coast.

III. Deciduous White Oaks of North America.

The oaks with which we are familiar in this part of the country are of the lobed-leaf type. Geographically, at least, there are three parts to this group,—the eastern, the Rocky Mountain, and the Californian lobed-leaf oaks. It is not clear, however, whether or not these geographical groups can be separated taxonomically. They may be parallel groups, cut off from one another comparatively recently; or, possibly, the Californian group may be more closely related to the deciduous oaks of Europe (type *Q. robur*) than it is to the oaks of the Rocky Mountains and the east. The habit, leaf form and texture, and bud form of the Californian oaks have suggestive resemblances to those of the English oak; and it is perhaps not venturing too much to speculate as to whether these oaks, like certain other forms on our Pacific slope, may not have their closest relatives, not in America at all, but in Europe. There is besides at least one oak in California, *Q. sadleriana,* which appears to find its

nearest relatives in the modern Asiatic oaks, which were mentioned as having probably reached Asia in Tertiary times from the eastward. The *gambelii* group in the Rockies and the Atlantic group are apparently the separated branches of the latest developed white oaks (and the Californian oaks are perhaps a third corresponding group), which before glaciation may have succeeded in covering the greater part of the continent. Glaciation left survivors of this forest, it would seem, in two parts of the land—mountainous regions which projected above the ice—the southern Rockies, and the southern Alleghanies. From the one *Q. gambelii* has spread northward, keeping rather closely to the mountains and differentiating numerous but similar species; while from the other the early species (possibly *lyratiformis* and *minor*) have recovered an enormous stretch of territory, and have produced a correspondingly large number of varied species.

IV. White Oaks of Eastern North America.

The white oaks found east of the Rocky Mountains comprise the following species (see key):

1. *breviloba* *durandii*	2. *lyrata* *bicolor* *macrocarpa*
3. *chapmani* *minor* *margaretta* *alba*	4. *michauxii* *prinus* *muhlenbergii* group.

These species are all of the deciduous, thin-leaved type of *Leucobalanus*, except that *durandii* and *breviloba*, in ranging from Alabama west and south into northern Mexico, show a series of transitions towards the smaller, more entire, evergreen type of leaf. It might be that a careful study of these forms would show them to be transitional in other features also. Their range seems to indicate an ancient center of distribution in the southwest; this again is in sharp contrast to all the other species, which may be referred to a more recent center in the southeast. In short, there seem to be

several reasons for marking off rather sharply *durandii* and *breviloba* from the remainder of the species present in this area, and for suggesting the possibility that they may be a relic from the time of the differentiation of this deciduous section of *Leucobalanus*.

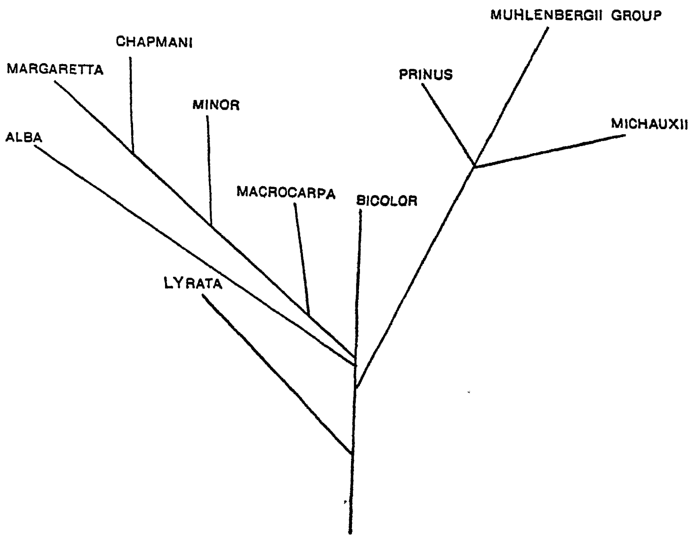
The remainder of the group has a very wide range. It touches the Rockies in Canada, and reaches Texas, Florida, and Maine. Nevertheless, it is almost true to say that every one of the species includes in its range the region of the southern Alleghanies. This region certainly seems to have been a center of distribution after the retreat of the ice fields, for this as well as for certain other groups of plants and animals (*Cambarus*, and the Unionidæ, for instance). The present distribution must have been largely achieved by the Pleistocene, for late Pleistocene fossils indicate a range broadly similar to that of the present.

The species, aside from (1) *durandii* and *breviloba*, fall into three main groups—(2) *macrocarpa* group, (3) *minor* group, (4) *prinus* group. Their relation to one another is not entirely clear. The *macrocarpa* group in some ways holds a central position, which suggests that it may be the oldest. So do the *persistent stipules* of all members of the group; this is without any doubt a primitive character. Its species moreover have the widest range, *macrocarpa* extending in the north to Saskatchewan and Maine, and in a great southward curve with its lowest point well down the Mississippi Valley; south of this it is replaced by *lyrata*. Again, Tertiary leaf-prints which have been referred to deciduous *Quercus* are limited thus far to types resembling *lyrata* and *minor*. (Cockerell's species *lyratiformis* from the Florissant beds is now reported from the John Day Basin, Oregon, where Knowlton also recognizes leaves of the type of *minor*.) There are so many suggestions of this sort that at present we must assume the *macrocarpa* group to be nearest to the ancestral type; and, though the fruit is aberrant, *lyrata* may well stand near the base of the group.

The *minor* group, or at least *minor* itself, has some affinities with *bicolor* and *macrocarpa*. Its wide range and the Tertiary occurrence of this or a similar species show that it has valid claims to antiquity. Whether *alba* belongs in this group is uncertain; it is difficult to see reasons for connecting it closely with any other species. *Mar-*

garetta, regarded by some as a good species, but which has often been regarded as an *alba-minor* hybrid, suggests such a relationship, but this is more or less doubtful.

The clearest and most highly differentiated group is that of the chestnut oaks. It may be connected with the more typical forms through forms such as *bicolor* (shape of leaf) and *lyrata* (bud-scales). That the serrate leaf is secondarily derived, through a lobed form, and not a persistence of the serration found in older portions of the genus is perhaps not proven; the tendency to lobation rather than serration on young shoots, as well as the general relation of the chestnut oaks to the other oaks of this region make it, however, highly probable.



The above diagram may make more concrete these suggestions concerning relationships.

Key to Deciduous White Oaks of Eastern North America.

Leaves deciduous, lobed or dentate, not spinulose.

I. Leaves lobed.
- *A.* Stipules persistent; buds more or less acute.
  - 1. Twigs slender, smooth. *Lyrata.*
  - 2. Twigs stout, pubescent.
    - *a.* Fruit sessile, larger; cup usually deeper and fringed. *Macrocarpa.*
    - *b.* Fruit pedunculate, smaller; cup more shallow, seldom fringed. *Bicolor.*
- *B.* Stipules deciduous; buds rounded.
  - 1. Twigs smooth. *Alba.*
  - 2. Twigs pubescent.
    - *a.* Leaves deeply five-lobed, pubescent below. *Minor.*
    - *b.* Leaves undulate, glabrous below *Chapmani.*

II. Leaves dentate.
- *A.* Buds less elongate, leaves narrower, widest near middle. *Muhlenbergii.*
- *B.* Buds more elongate, leaves broader, widest above middle.
  - 1. Cup scales free at tips only; upper scales very small. *Prinus.*
  - 2. Cup scales free; upper scales often forming a fringe to cup. *Michauxii.*

Description of Plates.

Plate IV. Buds of the rounded type, without stipules. × 3.

Fig. 1. Q. alba (Urbana, Illinois).
Fig. 2. *Q. minor* (collected by H. H. Bartlett, Maryland).

Plate V. Buds of the more acute type, stipules persistent. × 3.

Fig. 1. *Q. macrocarpa* (Urbana, Illinois).
Fig. 2. *Q. bicolor* (Urbana, Illinois).

Plate VI. Buds of the elongated, chestnut oak type. × 3.

Fig. 1. *Q. prinus* (collected by H. H. Bartlett, Maryland).

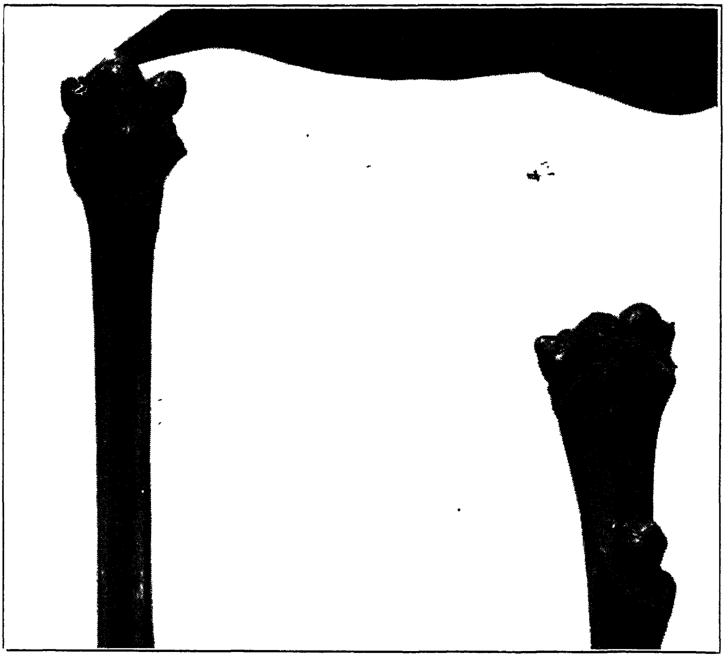


FIG. 1.

FIG. 2.

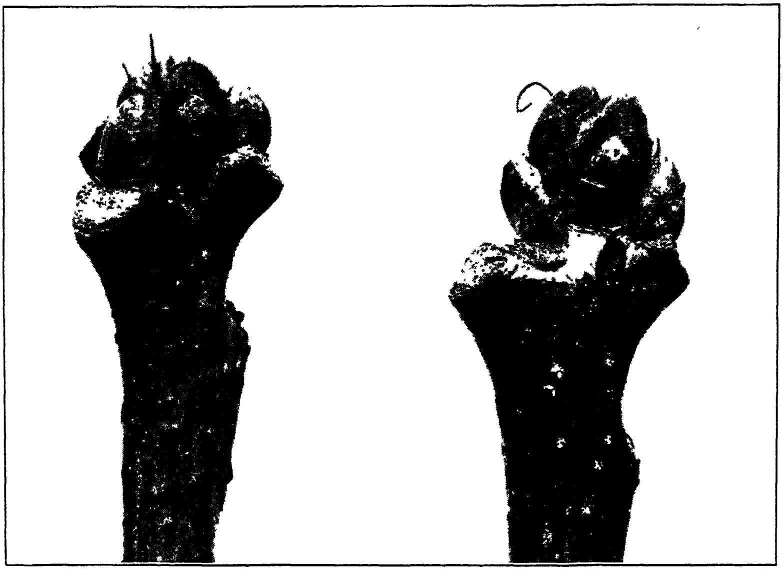


FIG. 1.

FIG. 2.

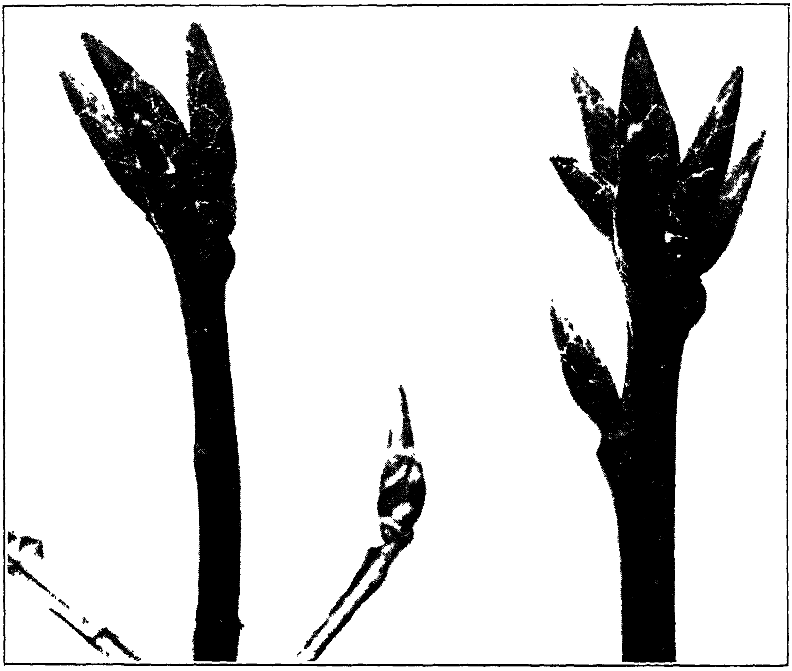


FIG. 1.

BIBLIOGRAPHY.

Berry, E. W.

1906. A Note on Midcretaceous Geography. *Science,* N. S., Vol. XXIII., pp. 509–510.

Brenner, Wilhelm.

1902. Klima und Blatt bei der Gattung Quercus. Flora, Bd. 90, p. 114.

1902. Zur Entwicklungsgeschichte der Gattung Quercus. Flora, Bd. 90, p. 446.

Candolle, Alphonse de.

1868. Prodromus Systematis Naturalis Regni Vegetabilis, Vol. XVI, pp. 1–109. Paris, Victoris Masson et Filii.

Engler, A., und Prantl, K.

1894. Die Natürlichen Pflanzenfamilien. III. Teil, 1 Hälfte, p. 47. Leipzig, Engelmann.

Gray, Asa.

1872. Address to the American Association for the Advancement of Science, *Proceedings A. A. A. S.,* Vol 21, p. 1.

Knowlton, Frank Hall.

Fossil Flora of the John Day Basin, Oregon. Bull. U. S. Geol. Survey, No. 204.

Liebmann, F. M., and Oersted, A. S.

1869. Chênes de l'Amérique tropicale. Leipzig, L. Voss.

Saporta, le Marquis G. de.

1888. Origine paléontologique des arbres cultivés ou utilisés par l'homme. Paris.

Sargent, Charles Sprague.

1895. The Silva of North America. Vol. VIII. Cupuliferæ. Boston and New York, Houghton, Mifflin and Company.

Scharff, R. F.

1912. Distribution and Origin of Life in America. New York, Macmillan Company.

Schottky, E.

1911–12. Die Eichen des extratropischen Ostasiens und ihre pflanzengeographische Bedeutung. *Bot. Jahrb. f. Systemik, Pflanzengeschichte, und Pflanzengeographie,* Vol. 47, pp. 617–707.

von Ettingshausen, C., und Krasan, Franz.

1889. Beiträge zur Erforschung der Atavistischen Formen an Lebenden Pflanzen und ihrer Beziehungen zu den Arten ihrer Gattung. Denkschriften der Kaiserlichen Akademie der Wissenschaften (Wien). *Mathematisch-Naturwissenschaftliche Classe,* Bd. 56, p. 47.

A NEW FORM OF NEPHELOMETER.

By J. T. W. MARSHALL and H. W. BANKS, 3D.

(*Read April 23, 1915.*)

The nephelometer (Gr. νεφέλη, a cloud), an instrument for the quantitative determination of small amounts of material in suspension, has attracted considerable attention of late, although the principles involved are by no means new. Since the time of Gay-Lussac attempts have been made to estimate small quantities of material by the turbidity or opalescence of their suspensions. This was generally done by comparing the suspension with a graded series of known suspensions prepared in the same way, and the comparison was made by looking through a column of the liquid and noting the turbidity, or by observing the opalescence, that is, the light reflected from the minute particles when the liquid is illuminated by a powerful beam of light. It is evident that matter in smaller quantities or in a finer state of subdivision may be recognized more easily by the opalescence than by the turbidity of its suspension. That even excessively minute particles possess the ability to diffract light has been shown by the ultramicroscope, while by the Faraday-Tyndall convergent beam of light, the optical in-homogeneity of solutions of crystalloids has been detected.

T. W. Richards in the course of atomic weight determinations in 1894[1] devised a simple instrument to enable the opalescence of very dilute suspensions of silver bromide to be more readily observed, and in a measure, quantitatively determined. Ten years later, Richards and Wells[2] improved the instrument optically and suggested its applicability to suspensions of substances other than the silver halides. Their actual determinations, however, seem to have been arrived at by a process of approximation; that is, the unknown was compared in the instrument to a suspension of known concentration, and from these readings a first approximation of its strength was calculated. A new standard of more nearly the same concentration as the unknown was then prepared

[1] *Proc. Am. Acad.*, XXX., 369, 1894.

[2] Richards and Wells, *Am. Chem. Jour.*, XXXI., 235, 1904.

and comparison again made. This process was repeated until a standard was obtained which when precipitated under the same conditions and compared in the instrument with the unknown gave the same amount of opalescence. The postulate involved, that the same quantities of material precipitated under identical conditions give equal opalescences, is undoubtedly correct, but the method is somewhat tedious in application, although good accuracy was obtained in about three approximations.

Wells in 1906[3] published the results of numerous experiments in which silver chloride was precipitated under different conditions, showing the influence of electrolytes both on the maximum opalescence developed and on the time required for this maximum to be reached. He came to the natural conclusion that the amount of light reflected varies not only with the quantity of material in suspension but also with its state of subdivision. In this investigation he used the Richards instrument of 1904 except that for the usual standard suspension he substituted fixed standards of ground glass as reflecting surfaces.

P. A. Kober[4] in 1913 took up the problem of determining quantitatively by the use of the nephelometric method, proteins and other substances occurring in biochemical investigations for which the ordinary gravimetric methods are either very tedious or inadequate. He used an instrument on the principle of the Richards nephelometer but adapted to the framework and optical parts of the Duboscq colorimeter. In comparing the opalescences of suspensions differing considerably in concentration, he observed that the readings were not quite inversely proportional to the concentration of matter in suspension, and from a large number of experiments with suspensions of different substances he developed an empirical formula expressing the relation between scale readings and concentration. This formula holds very well for ratios up to 1 : 3. He has successfully applied his instrument and method to the determination of a number of organic substances such as casein in milk, uric acid, and other purines. The nephelometer in various modifications has been used by W. R. Bloor to determine the fat

[3] Wells, *Am. Chem. Jour.*, XXXV., 99, 1906.

[4] P. A. Kober, *Jour. Biol. Chem.*, XIII., 485, 1913.

in blood, by McKim Marriot for acetone, and by S. S. Graves in ammonia determinations.

A number of instruments and methods have been devised for determining the amount of substance in suspension by the turbidity of its solution and these find considerable use in industrial chemistry. While the theory underlying this method is undoubtedly simpler than the nephelometric theory, it may easily be seen from the following considerations that the turbidimeter cannot equal the nephelometer in delicacy or sensitivity. Let us suppose that a standard as used in the turbidimeter absorbs about 10 per cent. of the light, then an unknown of twice the concentration will absorb about twice that quantity. However, it is not the amount of light absorbed, but the amount transmitted that is observed in this instrument; consequently the quantities measured would be in the ratio of about 9:8. The reflected lights measured in the nephelometer on the other hand would be nearly in the ratio of 1:2. Clouds which may be measured with considerable accuracy in the nephelometer show very slight absorption when observed by transmitted light in the turbidimeter.

Our reason for devising a new nephelometer may be made more apparent by a brief review of some of the considerations involved in the use of such instruments. The following are the chief factors involved in the amount of light reflected by an opalescent solution. First, the amount of substance in suspension. Second, its physical state, *i. e.*, the number and size of the particles, and their albedo which depends upon their own refractive index and that of the medium in which they are suspended. The amount of light observed is again modified by the fact that the light from any particle is reduced by an amount dependent upon the absorbing power of that part of the liquid above the particle. Thus we receive less light from the bottom layers of the suspension than from those nearer the top. This complex relation between reflection and absorption demands less consideration when the lengths of the illuminated columns are kept equal than when they are varied. As far as we are aware, in the nephelometers hitherto described the light from the two tubes has been equalized by changing the lengths of the illuminated columns of suspension. Although in purely

empirical work the elimination of this factor is not of very great importance, the theoretical consideration of the problem is greatly simplified thereby.

As Wells states, the opalescence of a liquid containing a definite amount of substance in suspension will, owing to the greater total reflecting surface, increase with the continued subdivision of the particles until these reach a limiting size. Rayleigh has pointed out this fact in a mathematical dissertation on the blue color of the sky, stating that as the particles approach the size of a wave length of light their reflecting power decreases. He shows that for very minute particles the amount of light reflected should vary as the sixth power of their radius. The maximum opalescence of the solutions as used in a nephelometer seems, however, to be developed when the particles are much smaller than a wave length of light—in fact of ultramicroscopic size.

The amount of reflected light lost through absorption is also a function of the number and size of the particles.

It is evident that as the refractive index of the medium approaches that of the particles, the amount of light reflected will decrease until, when the two refractive indices become equal, there will be no reflection. This phenomenon may be observed if powdered glass be suspended in a mixture of carbon disulphide and benzol.

With a view to determining some of the underlying laws of opalescent solutions, we undertook to design a nephelometer better adapted both to theoretical and to practical work than those in use at present. By using equal columns of suspension and actually measuring the reflected lights with a suitable photometer, not only is one of the variables eliminated, but also we are enabled to determine the absolute ratio of the lights reflected by various suspensions. The photometric part of the apparatus consists of a wedge of neutral tinted glass by which the light from one of the suspensions may be controlled; and a suitable optical arrangement for observing the two beams of light. A Lummer-Brodhun prism would serve this purpose admirably, but by a simple arrangement of mirrors, a field far more sensitive than that of the Duboscq colorimeter may be obtained.

Briefly the design of the instrument is as follows: The suspensions to be compared are contained in the two cells *A* and *B* shown in the accompanying diagram (Figs. 1 and 2). These consist of cylindrical glass tubes about 4 cm. high and 1 cm. in diameter. A glass plate is sealed into one end, while the other end is covered by a circular plate of glass slightly countersunk and held in place by caps of black fiber. These prevent stray light reflected from the edges

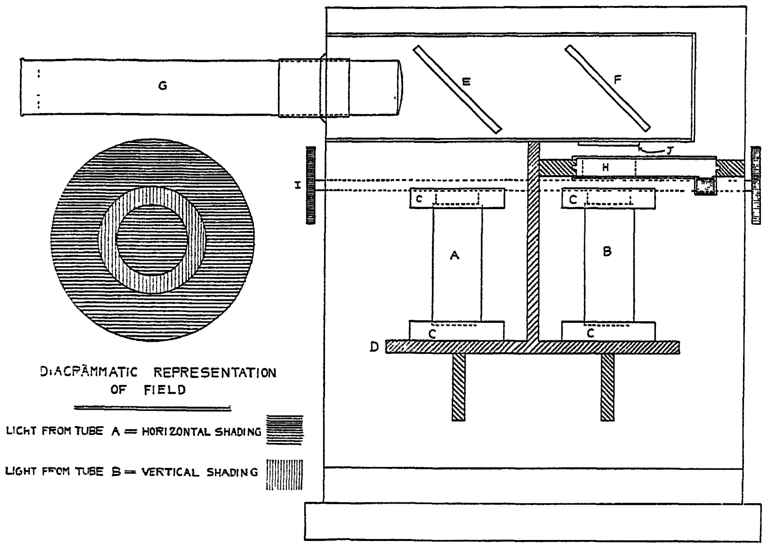


FIG. 1.

of the glass from entering the instrument. Difficulties arising from the agitation of the liquid by plungers are also thus avoided by having the cells completely enclosed. The cells rest on a shelf and are illuminated normal to their axes by a parallel beam of light from a 100 Watt lamp. The rays reflected from the suspended particles pass upward to the two mirrors *E* and *F* whence they are reflected into the magnifying eyepiece *G*. This is focused on mirror *E*. A circle cut through the silvering of mirror *E* permits the juxtaposition of the light from tubes *A* and *B* thus giving the eyepiece a field which is represented diagrammatically in the accompanying illustration. Photometric balance is effected by changing the intensity of the light from tube *B* by means of the sliding wedge of

neutral tinted glass *H*. This adjustment is made by the thumb-screw *I* and the position of the wedge is read on a scale mounted alongside (not shown in the diagram). A compensating wedge wedge may be placed at *J*, but unless the sliding wedge *H* is of fairly steep pitch, this is unnecessary, as the illumination of the field is sufficiently uniform without it. All parts of the instrument from which extraneous light may be reflected are painted a dead black.

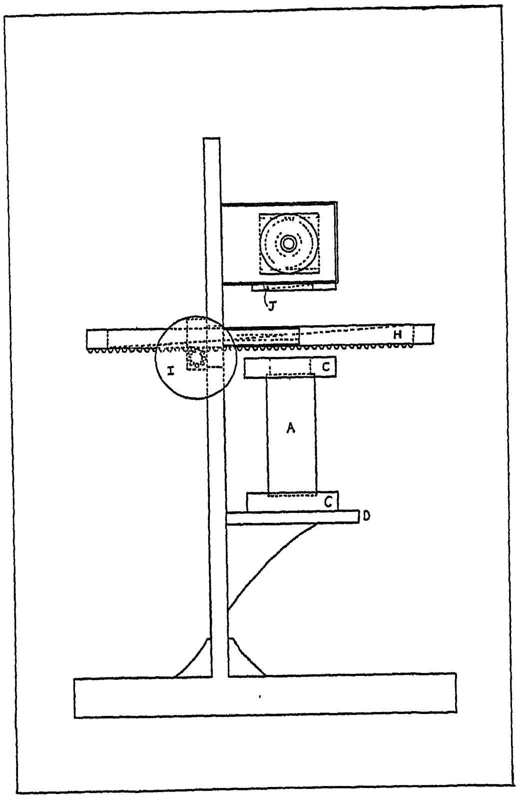


FIG. 2.

The construction of this instrument was delayed owing to difficulties encountered in securing neutral tinted glass. While awaiting its completion we decided to improvise a nephelometer in which several minor changes have been made. Among these may be mentioned the substitution for the glass wedge of a metal plate in which was cut a tapered slot. With this instrument we undertook some

work of rather an empirical nature along biochemical lines. Kober in one of his papers suggested the possibility of a nephelometric determination of albumin in urine, and a turbidimetric method for the same has been developed by Folin and Denis.[5] We therefore decided to apply our instrument to this problem. The standard was prepared from fresh normal human serum as recommended by Folin and Denis, and was standardized by nitrogen determinations and also by gravimetric determination of the heat coagulable proteins.

Difficulty was encountered at the start in comparing in the nephelometer albumin precipitated in the urine with that precipitated in the solution of standardized blood serum, on account of the difference in color due to the urinary pigments. In order to eliminate this interference of color, and also to obtain identical conditions of precipitation for both urine and standard, two equal portions of the urine of from 0.3 c.c. to 10 c.c. depending upon the quantity of albumen present, were taken. To one of these a known amount of standard was added (about 0.5 c.c. of 0.4 per cent. solution of serum protein). Both were then diluted to 75 c.c. with water and finally made up to 100 c.c. by the addition of a 7.5 per cent. solution of sulpho-salicylic acid. This gave a final concentration of 1.87 per cent. sulpho-salicylic acid, while the amount of protein varied from 2 to 5 mg. in 100 c.c. The resulting opalescent solutions were then compared in the nephelometer, the tube containing the urine plus standard being placed under the tapered slot. The light from this tube was then progressively diminished by adjustment of the slotted plate until photometric balance was obtained. From a scale with suitable vernier the position of the plate was read. As the theory has not advanced far enough as yet to permit of a purely formulative interpretation of the readings, the ratio of the concentrations of the two suspensions was determined from a curve. This curve had been obtained by plotting against the concentrations the scale readings obtained when known ratios of serum, made up with albumin free urine and precipitated with sulpho-salicylic acid under identical conditions, were compared. From the ratio R determined by means of the curve, the amount X of albumin originally present in the urine was found by the formula $R = \frac{X}{X+n}$ where n is the amount of

[5] Folin and Denis, *Jour. Biol. Chem.*, XVIII., 273, 1914.

serum albumin added. Quantities of urine and of standard were so taken that R would be in the neighborhood of one half. Urines containing large amounts of albumin (1 per cent. or over) were, after suitable dilution, compared directly with standard serum solution. In the case of such urines the high dilution necessary to obtain suitable nephelometric clouds eliminated the differences of color mentioned above. The results were compared with gravimetric determinations made according to Scherer's method. The clear filtrates from the coagulated protein were tested with sulpho-salicylic acid to make sure that none of the protein remained in solution. Duplicate gravimetric determinations gave good agreement. It was immediately evident that the nephelometric determinations were considerably higher than the gravimetric. Moreover, in the case of determinations on daily specimens of urine from one patient, the nephelometric results were consistently about 25 per cent. higher than the gravimetric, while in a similar series from another individual the ratio between nephelometric and gravimetric determinations was very variable, ranging from 1 to about 1.5. This at once suggested that the different proteins of the serum, while closely related chemically and equally precipitable by sulpho-salicylic acid, might give, in the nephelometer, clouds of different intensities. It is a significant fact that in the case of patient R where the ratio of nephelometric to gravimetric was variable, half saturation of the urine with ammonium sulphate gave a considerable precipitate of globulin.

In order to determine what differences might exist between the opalescences produced by equal amounts of the various serum proteins on precipitation with sulpho-salicylic acid under identical conditions, albumin, euglobulin, and pseudoglobulin were prepared from horse serum. Solutions of these when compared in the nephelometer gave surprisingly different results. The albumin gave about two and one half times as great an opalesence as the euglobulin and about three times as great as the pseudoglobulin. Compared with casein[6] suspensions, the following ratios, expressing the light reflect-

[6] As standard solutions of casein are easily prepared and also give very satisfactory clouds on precipitation with sulpho-salicylic acid, this substance forms a very convenient standard of reference in nephelometric work with various proteins.

ing power of equal amounts of these proteins, were found: Casein $=0.67$ albumin; euglobulin $=0.63$ casein; pseudoglobulin $=0.51$ casein.

From the results experimentally obtained with various urines and from the differences in the clouds produced by equal amounts of the serum proteins, it may be seen that the nephelometric comparison of urine, in which these proteins may occur in varying amounts, with any definite standard such as serum cannot give a determination of the total protein. We hope by the use of specific precipitants to apply the nephelometric method to the separate determination of albumin and globulin in urine. This may be of value in diagnosis.

As the object of this paper has been to consider mainly the design of the instrument and the reasons for this design, the discussion of its application to the determination of albumin in urine has of necessity been hardly more than a suggestion of the work along that line. The results of the investigation of this particular problem with the experimental details, will be published shortly.

Summary.

1. The previous work in nephelometry has been briefly reviewed and the underlying principles of the nephelometric and turbidometric methods have been compared.

2. A new form of nephelometer has been described in which columns of suspension of equal lengths are used. The lights reflected are equalized and compared by means of a movable wedge of neutral tinted glass. Juxtaposition of the two emergent beams is secured by mirrors.

3. The variations found in preliminary experiments on the nephelometric determination of albumin in urine indicated that equal amounts of the various serum proteins might give different opalescences. Investigation showed that upon precipitation with 1.87 per cent. of sulphosalicylic acid, the same concentrations of serum albumin and serum globulins gave widely different clouds.

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THE RÔLE OF THE GLACIAL ANTICYCLONE IN THE AIR CIRCULATION OF THE GLOBE.

BY WILLIAM HERBERT HOBBS.

(*Read April 24, 1915.*)

CONTENTS.

The Fixed Anticyclones Above Existing Continental Glaciers.

The Anticyclones as Agents of Glacier Alimentation.—In two monographs published in 1910[1] and later in my "Characteristics of Existing Glaciers,"[2] a theory of fixed glacial anticyclones centered over the snow-ice masses of Greenland and Antarctica was put forward upon the basis of a comprehensive review of the results of polar exploration. This theory furnished an explanation for the nourishment of these inland-ice masses through adiabatic melting and vaporization of the ice particles of the cirri, as they are drawn down within the vortex of the anticyclone, and the precipitation of this moisture, generally as fine ice needles, when it comes into contact with the glacier surface and the cooled air layer immediately above it. The obvious application of this theory of alimentation to the even greater continental glaciers of the Pleistocene and earlier glacial cycles, was made in a separate contribution.[3] For these fixed anticyclones themselves, which are deserving of a special name, so much evidence has now accumulated that their existence can hardly be disputed, though differences of opinion will no doubt arise concerning their dominance over or dependence upon the usual migrating cyclonic and anticyclonic movements in the atmosphere.

The Northern and Southern Glacial Anticyclones Compared.—That a great fixed anticyclone exists within the south polar region

[1] "The Ice Masses on and About the Antarctic Continent," *Zeitsch. f. Gletscherk.*, Vol. 5, 1910, pp. 107–120; "Characteristics of the Inland-ice of the Arctic Regions," *Proc. Am. Philos. Soc.*, Vol. 49, 1910, pp. 96–109.

[2] Macmillan & Co., New York and London, 1911, Chaps. IX. and XVI. and afterword.

[3] W. H. Hobbs, "The Pleistocene Glaciation of North America Viewed in the Light of Our Knowledge of Existing Continental Glaciers," *Bull. Am. Geogr. Soc.*, Vol. 43, 1911, pp. 641–659. When this theory of alimentation was announced, I supposed it to be new to science. Professor Hans Crammer has since called my attention to a little-known paper by Fricker published as early as 1893, in which a similar idea was made as a suggestion and at a time when there was little known which could have been cited in its support. (Dr. Karl Fricker, "Die Entstehung und Verbreitung des antarktischen Treibeises," Ein Beitrag zur Geographie der Südpolargebiete. Leipzig, 1893, p. 96; also "Antarktis," Scholl und Grund, Berlin, 1898, pp. 187–188.)

seems to have been early recognized by a number of scientific men, due especially to the writings of the late Sir John Murray, Bernacchi and Buchan. By them it was, however, assumed that this condition was determined in some manner by the earth's southern geographic pole, and was not connected with the inland-ice. A like natural tendency to regard movements within the lower atmosphere as determined primarily by their positions relative to parallels of latitude, is more or less general. As an illustration, it is generally assumed upon the basis of few and scattered observations within all save the central European areas, that the ceiling of the troposphore in its descent from the equatorial regions reaches its minimum altitude above the geographic poles, though it is far more probable that in the northern hemisphere at least its minimum of altitude is to be found to the southward above the continental glacier of Greenland. In the southern hemisphere the Antarctic continental glacier is probably centered near the pole, and in consequence conclusions drawn from geographic positions are there relatively indecisive. During the winter season the great deserts of moderate latitudes become likewise the loci of anticyclones. Their influence upon the general circulation within the earth's atmosphere should be, however, relative to that of the inland-ice small by comparison. It is because the inland-ice masses have a domed surface that they permit the air which is cooled by contact to flow outward centrifugally and so develop at an ever accelerating rate a vortex of exceptional strength. As already pointed out in my earlier papers, this is one of the essential conditions for the formation of strong glacial anticyclones.

Their Strophic Action Believed to be Dependent upon an Automatically Recurring Disturbance of Balance Between Opposing Forces.

The Refrigerating Air Engine.—The strophic action of glacial anticyclones is one of their most marked characteristics, and would appear to be dependent upon the shield-like form of the glacier surface. Opposed to each other are here the abstraction of heat from the air above the glacier surface tending to make it slide off radially, and the increase of temperature due to resulting conden-

sation. Unlike the latter, which is determined by the measure of the vertical component of its fall, the contact cooling is in direct ratio to the time the layer of air rests upon the snow-ice surface. Conditions of calm therefore favor cooling and descent of air currents, as high wind velocity, does the warming and consequent retardation or even reversal of the descending current. It is not surprising, therefore, that the strophic glacial storms are initiated in calm conditions, "work themselves up" or become accelerated to accord with the acceleration of velocity of bodies sliding upon inclined surfaces (here further accelerated by increasing slope toward the margins), and bring about their own extinction when the air passes over the surface too rapidly for surface cooling to exceed or equal adiabatic warming. The sudden check in the outward flow of air, which is one of the most striking features of these strophic movements, in turn promotes new surface cooling and causes the precipitation of fresh snow within the zone of near contact to ice, thus often taking place with the sun but little obscured. In the automatic recurrence of similar movements the glacial anticyclone thus bears considerable resemblance to the hydraulic ram.

The Lines of Evidence for Fixed Glacial Anticyclones.

The Earlier Evidence.—The observational evidence which in earlier papers was adduced in support of the existence of the glacial anticyclone above continental glaciers, was drawn chiefly from the then available reports upon exploration of the inland-ice masses of Greenland, Antarctica, and Northeast Land (Spitzbergen). This evidence may be profitably summarized under the following heads:

1°. Centrifugal flow of surface air currents above inland-ice masses.

2°. Outward (centrifugal) sweeping of surface snow largely derived from the central areas, and its deposition and accumulation as a marginal fringe about the inland-ice.

3°. Snow in large part wind-driven above the sloping portions of the ice mass.

4°. Sudden warming of the air at the end of the blizzard—foehn effect in descending currents.

5°. Behavior of upper air currents and movements of the cirri.

6°. The evolution of the Antarctic blizzard and its termination.

7°. Areas of relative calm corresponding to the flat central bosses of the ice domes.

8°. Air highly charged with moisture within the flat central area of calms, and precipitation of snow or ice near the glacier surface.

Confirmation in Later Exploration.—In the three years which have elapsed since the appearance of my "Characteristics of Existing Glaciers," important new explorations have been carried out; the inland-ice of Antarctica has been twice penetrated to the southern geographic pole and new areas have been explored; several crossings of Greenland have been made along new routes; and full reports upon some earlier explorations have become available. It is proposed, therefore, to review the evidence and show how this has been enlarged by the recent observations; as well as to add evidence along hitherto undeveloped directions. Such a discussion of the evidence seems to be called for at the present time, since in a paper recently read before the Royal Meteorological Society, Brooks has presented this theory as his own, merely citing my book for references to glacial conditions.[4]

Evidence for More than One Anticyclonic Center Above Each of the Greater Areas of Inland-Ice.

Greenland.—The three transections of the Greenland continent which have now been made within the central and southern portions, have revealed the fact that there are at least two higher plains upon the snow-ice surface which are separated by a depression. This depression clearly lies to the northward of de Quervain's route, since his summit level is considerably lower than that of either Nansen or Koch and Wegener, though like Nansen's, his highest point is found near the east coast. The southern of the two nourishing centers of the Greenland ice-sheet is thus located toward the east coast and south of the Arctic circle, whereas the other center lies toward the west coast from the medial line of the continent,

[4] Charles B. Brooks, "The Meteorological Conditions of an Ice Sheet and their Bearing on the Desiccation of the Globe," *Quart. Jour. Roy. Meteorol. Soc.*, Vol. 40, 1914, pp. 53–70.

and in an as yet undetermined latitude, though certainly well to the northward of Disco Island (Fig. 1).

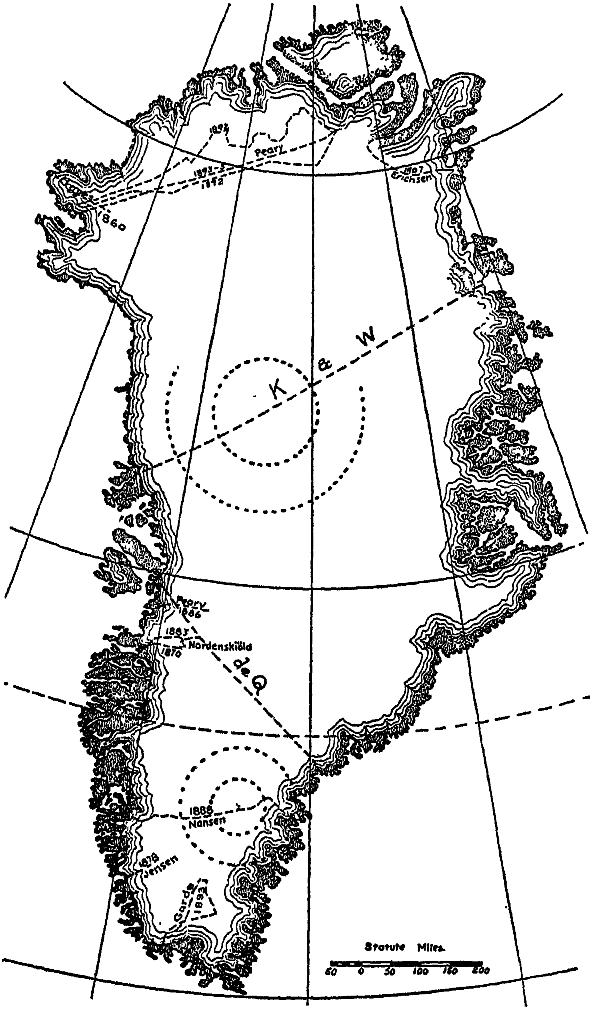


FIG. 1. Sketch map of Greenland to show roughly the position of the ice domes within the central and southern portions.

Antarctica.—This discovery that Greenland is provided with more than one nourishing center for its inland-ice, is wholly in accord with what has now been learned concerning the Pleistocene continental

glaciers of North America, which had the Keewatin, Labradorean and Patrician nourishing centers that repeatedly waxed and waned so as to reach their several maxima at different times (Fig. 2).

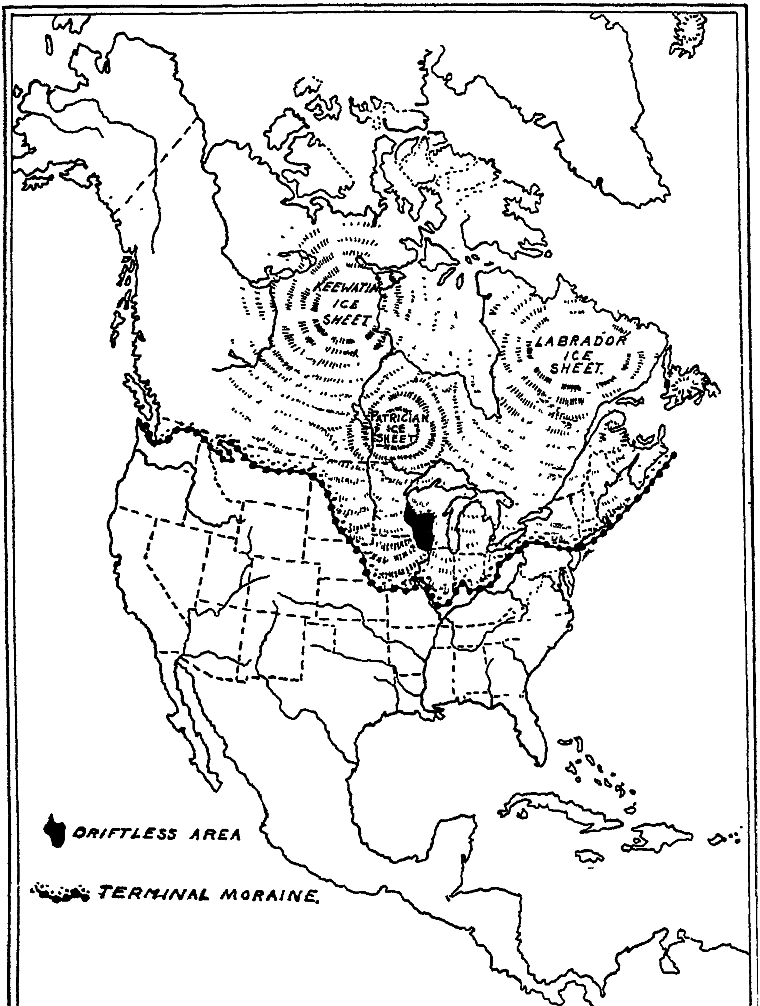


FIG. 2. Map showing the known anticyclonic centers of the Pleistocene continental glacier of North America.

From the Antarctic region the experiences of Mawson strongly indicate a near-by anticyclonic area probably located near the mag-

netic pole.[5] Within a vortex of this nature the wind velocity is determined by angular velocity multiplied into the radius, and hence one of relatively small dimensions should exceed in vigor one that is spread over a vast field and in which the steeper marginal area bears a smaller ratio to the whole. Mawson has expressed the belief that his base was near the center of a permanent anticyclone.[6]

The Centrifugal Flow of Surface Air Currents Above the Inland-Ice Masses.

Early Evidence from Greenland.—In 1911 when my work on glaciers was published, evidence was available upon this from both the eastern and western coasts of southern Greenland in latitude 64° (Nansen), from west Greenland in latitude 69° (Peary and later de Quervain and Stolberg[7]), from northwest Greenland in latitude 78–83° (Peary), and from northeast Greenland in latitude 77° to 82° (Trolle). With the exception of the first and last mentioned, these data applied exclusively to the western coast where the prevailing surface winds come from the easterly quadrants.

Later Confirmation.—The later evidence for the centrifugal flow of surface air is ample and throughout confirmatory. De Quervain, who crossed the inland-ice in 1912 between the latitudes of 66° and 68°, found head winds while ascending the west slope, but winds from behind during his descent to the east coast.[8] Referring to the low temperatures and the wide diurnal temperature range within the central area, de Quervain says:

> "It is the cold air of this middle part which even in summer streams like water from off the high surface toward all margins, deviated to the right in consequence of earth rotation" (p. 137).

Measurements of snow temperature made at different depths show

[5] Sir Douglas Mawson, "Australasian Antarctic Expedition 1911–1914," *Geogr. Jour.*, Vol. 44, 1914, pp. 257–286.

[6] L. c., p. 69.

[7] The first Swiss expedition, which penetrated some seventy miles from the coast (A. de Quervain und A. Stolberg, "Durch Grönlands Eiswüste," Strassburg, 1909).

[8] A. de Quervain, "Quer durchs Grönlandeis, Schweizerische Grönland-Expedition 1912–13." Reinhardt, München, 1914, 196 pp., 15 pls., 37 figs. and map. Also personal communications.

how exactly the air temperature follows that of the snow (p. 94). The diary of the journey (pp. 85–104) shows that for the first three weeks on the inland-ice the wind blew almost uninterruptedly down slope from in front, became more variable and shifting on the plain with slope a few seconds of arc, and reversed direction and blew from the northwest soon after passing the divide, where slopes became 8′ of arc to the eastward.

Koch and Wegener in their transection of the Greenland continent at its widest section (between latitudes 72° and 73°) encountered essentially the same conditions, the outward blowing currents constituting a veritable succession of storms whose vigor increased toward both margins of the section.[9]

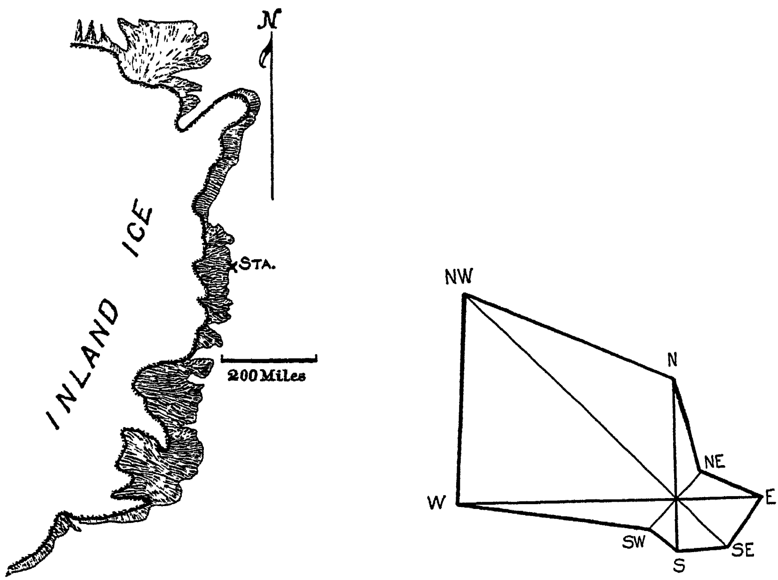


Fig. 3. Frequency wind-rose at Danmarks-Haven in northeast Greenland and (at the left) a sketch map showing location of the station with reference to inland-ice (after Wegener).

From northeast Greenland there was available at the time of my earlier discussions of the glacial anticyclones, only a preliminary

[9] J. P. Koch, "Unsere Durchquerung Grönlands 1912–1913," *Zeitsch. d. Gesellsch. f. Erdk. z. Berlin,* 1914; Alfred Wegener, "Vorläufiger Bericht über die wissenschaftlichen Ergebnisse der Expedition," ibid.

statement concerning the prevailing direction of surface winds at the Danish base near Cape Bismarck. More recently (1911) the full meteorological report by Wegener has been issued; and, confirming the earlier statement, shows that all strong winds come from the westerly (inland-ice) quadrants. The frequency wind-rose to cover the entire period of two years over which the observations extended, is reproduced in Fig. 3.[10] If the wind force had been taken account of, the easterly sections of the rose would have almost disappeared, since easterly winds are always light sea breezes, which at an elevation of only 1,000 meters have been completely overwhelmed by the northwest winds.[11] In this rose the dextro-rotatory deviation of the down-slope winds is apparent.

Early Evidence from Antarctica.—Over the Antarctic inland-ice the law of surface air circulation had been clearly indicated by the results of exploration at the time of my early discussion of the subject. The more important data had been derived from the sledge journeys of Captain Scott, Sir Ernest Shackleton, Professor David and Dr. von Drygalski. As early as 1902 Captain Scott had ascended the Ferrar glacier outlet to the inland-ice above the mountain rampart and pushed west southwestward over it for a distance of two hundred miles, ascending on ever decreasing grades to the farthest point attained, and encountering winds of nearly constant direction coming from the south-southwest. The prevalence of such winds was demonstrated by a single set of sastrugi which pointed in the same direction (see Fig. 4).[12] Shackleton on his polar journey ascended the Beardmore outlet and for a like distance of two hundred miles over the inland-ice found strong winds blowing from the southerly quarter and sastrugi pointed in the same direction. David pushed northwestward from Ross Sea over the inland-ice to the south magnetic pole, crossing over a crest in the ice and descending on low grades during the last stage before reaching the pole. Here the same rule of distribution of currents applies,

[10] A. Wegener, "Med. om Grönland," Vol. 42, 1911, pp. 324–326.

[11] Wegener, "Med. om Grönland," Vol. 42, 1909, pp. 73–75.

[12] For this and other references to work published before 1910, see "Characteristics of Existing Glaciers," Chapters XIV.–XVI.

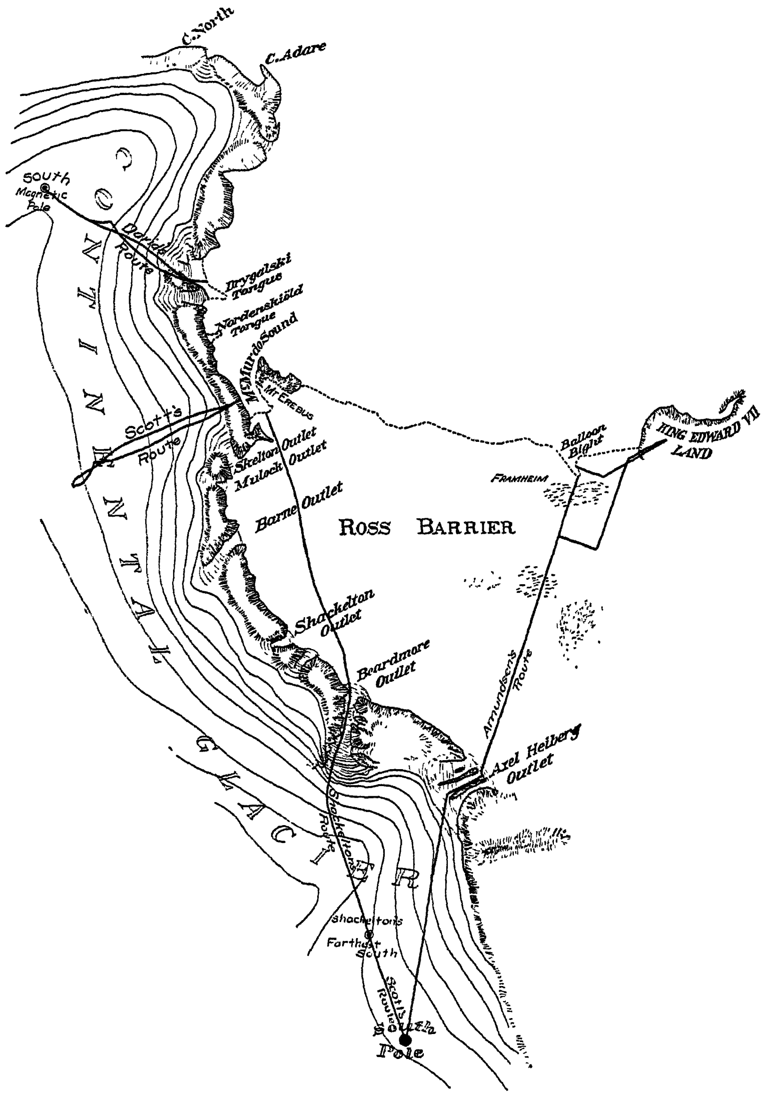


Fig. 4. Map of South Victoria land showing the sledge routes of Scott, Shackleton and David over the inland-ice.

for during the ascent he encountered northwest winds with sastrugi pointing toward the same quarter, but after passing the divide and on the down grade winds blew from behind—southeast. These observations were fully confirmed by the return journey

In Kaiser Wilhelm land also the report of von Drygalski shows that the prevailing winds blow downward off the inland-ice onto the sea and the shelf-ice in front, being deviated to the left—the prevailing strong winds are from the easterly quarter.

Later Confirmation.—Later data which bear upon the problem are derived from the Amundsen and the second Scott south polar expeditions, from the second German expedition to the Antarctic commanded by Filchner, and from the Australasian Antarctic expedition of 1911–14 under command of Dr., now Sir Douglas, Mawson. The route of Captain Amundsen passes through the mountain rampart which hems in the inland-ice, keeping a direction diagonal to it and for some distance after leaving the outlet behind taking a course near a high mountain range. The few data upon wind directions which he has jotted down in his narrative, appear to indicate local currents controlled by these mountains until he had reached the 88th parallel, where he entered an area of calms and light variable winds.[13] The second Scott expedition inasmuch as it followed the route of the earlier Shackleton expedition, has for the greater part of the distance, or until it entered the area of calms, served only to confirm the prevalence of outwardly flowing wind currents described by Shackleton.[14]

The recent Australasian expedition supplies evidence from a new quarter—the long coastal area near the Antarctic circle and to the westward of the Ross Sea, on which coast the inland-ice is not held in restraint by any barrier of mountains, as is the case in South Victoria Land. Along this coast, summer and winter alike, almost incessant storms blow off the ice onto the sea. These outwardly directed storm winds tend to keep the near sea area clear of pack-ice but offer great difficulties in the way of effecting a landing at all save those rare occasions when the force of the wind falls away.[15]

In Prince Regent Luitpold Land, where the later German expedition effected a landing upon the inland-ice—here likewise unconfined by a mountain wall and with partially detached shelf-ice in

[13] Roald Amundsen, "The South Pole," Vol. 2, 1913.

[14] "Scott's Last Expedition," Vol. 1, Chapters XVII–XIX.

[15] Sir Douglas Mawson, "Australasian Antarctic Expedition 1911–14," *Geogr. Jour.*, Vol. 44, 1914, pp. 257–286, maps and plates.

front—much the same conditions obtain, the wind blowing out to sea with velocities sometimes as high as 40 m.p.s.[16]

Outward Sweeping of the Surface Snow which Falls Over the Central Areas of the Ice Domes, and its Accumulation About Their Margins.

The Centrifugal Snow Broom.—What may be characterized as the centrifugal snow broom which sweeps out snow deposits from the central areas and collects them upon and about the margins of continental glaciers, is a necessary consequence of strong anticyclonic conditions; and its work is in evidence within all areas where inland-ice has been extensively explored.

From observations by Wegener, a wind velocity of 6–7 m.p.s. raises the snow lying upon the ground and sets it in motion along the surface at heights up to several decimeters (a foot or thereabouts). With wind velocities of 10–15 m.p.s (22.4–33.6 miles per hour) the migrating drift snow rises in a layer several meters in height and interferes seriously with seeing conditions. With velocities of 20 m.p.s. (44.7 miles per hour), the snow is carried to a height of 20 meters, or over sixty feet, and much higher in the lee of obstructions in its path.[17]

The Sweepings Below Outlets.—It is obvious that the results of snow drifting by centrifugal surface currents above inland-ice will be different according as the ice mass has been built up within a rampart of mountains (South Victoria Land and the greater part of Greenland), or as it has been allowed to shape itself independent of such retaining walls. In the former case the drift snow pours out along the courses of the outlet glaciers to form characteristic aprons at their bases,[18] or perhaps to produce definite fringing gla-

[16] "Deutsche Antarktische Expedition, Bericht über die Tätigkeit nach Verlassen von Südgeorgien," *Zeitsch. d. Gesellsch. f. Erdkunde z. Berlin*, 1913, p. 15; see also, *Kön. preussz. Meteorol. Institute,* Abh, Bd. 4, Heft II., p. 9.

[17] *Med. om Grönland,* Vol. 42, p. 345.

[18] In the light of observations by Scott, Shackleton and David in South Victoria Land, it seems probable that these apron-like snow deposits in the form of dry deltas are due largely if not wholly to this cause. Not only have explorers observed the rapid collection of the drift snow at the base of the Beardmore outlet, but this origin is probable for the reason that accord-

ciers such as have been described by Chamberlin[19] and Salisbury[20] from northwest Greenland, and by the Danes in northeast Greenland.[21]

Shackleton, who advanced over the inland-ice in his southern journey on a layer of granular surface snow, returned over a marble-like floor from which the snow had all been swept by the fierce blizzard encountered near his farthest south. On arriving at the Beardmore outlet, he found the lower forty miles of the stream buried deep under great drift accumulations. Scott on his last expedition was much less fortunate while on the plateau, and the burden of his diary is a prayer for strong wind to clear the surface. As is well known, he encountered heavy sweepings of powdery drift snow at the base of the Beardmore, both during his advance and on the return, and his floundering progress through this soft snow was a main contributing cause of the final disaster which overtook the expedition.

From what is known of the characters of freshly precipitated snow at different air temperatures, it is possible to rather definitely ascribe the enormous snow drifts which piled up for four consecutive days upon the Beardmore glacier apron as the *chasse neige* in process of melting as a result of adiabatic rise in temperature in descending currents. This snow, Captain Scott tells us, was the fine powdery type, though the temperature was phenomenally high (+ 27° — 31° F.), stuck to hair and beard, and produced pools of water everywhere.[22] On the return the snow here was soft, loose and sandy, and sledge work was like "pulling over desert sand."[23]

Marginal Accretions of Snow.—Valuable new observations which bear strongly upon this point, have been supplied in the preliminary report upon the crossing of Greenland by Koch and

ance of *surface* level is generally observed to characterize the junctions of tributary with main glacier streams wherever snow drifting plays only a secondary rôle.

[19] *Jour. Geol.*, Vol. 3, 1895, p. 579.

[20] L. c., p. 886.

[21] Koch und Wegener, "Die glaciologischen Beobachtungen der Danmark-expedition," *Med. om Grönland,* Vol. 46, 1912, Chaps. VI.–VII., pls. and figs.

[22] "Scott's Last Expedition," Vol. 1, pp. 335–339.

[23] L. c., p. 396.

Wegener. They report almost continual storms in all save the highest section of their journey, the wind descending the slopes and filling the air with drift snow. Within the marginal portions of their section, it was established that the finely granular surface layer of snow is joined abruptly to a more coarsely crystalline subjacent layer and corresponds to the annual deposit. This layer was by a series of measurements shown to vary in thickness from 20 cm., or about eight inches, in the central portion, to one half meter (or about two and a half times that thickness) near the east coast, and a meter (or five times this thickness) near the west coast. Schematically represented with grossly exaggerated scales, this distribution is expressed in Fig. 5. It was further determined that the snow

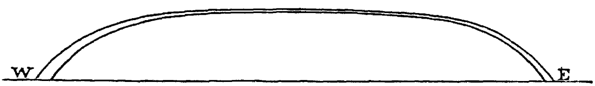


Fig. 5. Diagram to illustrate the marginal thickening of annual snow deposit upon the Greenland continental glacier due to drifting on radial lines.

deposit at Borg, the winter station upon the inland-ice though relatively near its margin, was less than on the coast to the eastward.[24]

Still more recently has appeared the preliminary report of Mawson upon the Australasian Antarctic expedition, in which he tells us that at the winter station on the margin of the inland-ice, the winds which blew down slope and off shore raised "a sea of drifting snow which poured fluid-thick over the landscape."

"For months the drifting snow never ceased, and intervals of many days together passed when it was impossible to see one's hand held at arm's length. The drift snow became charged with electricity and in the darkness of the winter night all pointed objects and often one's clothes, nose, and finger tips glowed with the pale blue light of St. Elmo's fire. . . . Such weather lasted almost nine months of the year. Even in the height of summer, blizzard followed blizzard in rapid succession."[25]

Where tongues of ice extended out to sea from the shore, snow collected upon them though the marginal slopes were swept free of it by the force of the blizzard.[26]

[24] A. Wegener, "Vorläufiger Bericht über die wissenschaftlichen Ergebnisse der Expedition," *Zeitsch. d. Gesell. f. Erdkunde z. Berlin,* 1914.

[25] Sir Douglas Mawson, "Australasian Antarctic Expedition, 1911–14," *Geogr. Jour.,* Vol. 44, 1914, pp. 269.

[26] Mawson, "The Home of the Blizzard," 1915, Vol. 2, p. 33.

Sudden Warming of the Air at the End of the Glacial Blizzard—Foehn Effect in Descending Currents.

Intensive Foehn Effective in Outlets.—This familiar foehn effect is so general a phenomenon about the margins of both the great continental glaciers that it has long been recognized.[27] The general rule holds that the temperature of the air rises as the blizzard is evolved.[28] Wherever a mountain rampart exists, the elevation of temperature becomes accentuated within the glacier outlets, and melting in Antarctica is almost unknown except under these conditions. An interesting example of this which has not before been emphasized, is supplied by Armitage, who on the first ascent of the Farrar outlet found a stream of water seven feet in width and nine inches deep flowing beside the ice.[29] The effect of similar currents of water was noted by David on his ascent to the plateau from McMurdo Sound. A remarkable instance, also, with long continuance of high temperature, is that above cited from Captain Scott's journal, while camped on the apron below the Beardmore outlet.

The Greenland Foehn.—The characteristic Greenland foehn has been subjected to a special study by Stade, the meteorologist of the Berlin Geographical Society's expedition to Greenland.[30] He finds that the temperature changes are much more pronounced during the winter season, the rise on March 5, 1893, having been 12° C. and probably much more within the space of a few minutes. Stade's conclusion is that these foehn winds are connected with low areas moving northward in the Davis Straits, the maximum of air temperature and the minimum of relative humidity corresponding either exactly or approximately with the minimum of pressure at the station. De Quervain's later studies would indicate that Stade's moving depressions may better be regarded as pulsations within a stationary low pressure area lying over Davis Straits and Baffin's

[27] See "Characteristics of Existing Glaciers," pp. 149–150, 268–271.

[28] Cf. Mawson, "The Home of the Blizzard."

[29] A. A. Armitage, "Two Years in the Antarctic," London, 1905, p.

[30] Dr. H. Stade, "Über Foehnerscheinungen an der Westküste Nordgrönlands und die Veränderung der Lufttemperatur und Feuchtigkeit mit der Hohe, Nach den Beobachtungen auf der Station Karajak, Grönland Expedition 1891–93," Vol. 2, 1897, pp. 501–533.

Bay. It would then seem more in harmony with the facts to reverse this conception and assume that the low pressure area is stimulated to greater vigor by the arrival of the strong winds of the glacial blizzard over the inland-ice.

Foehn Level and Foehn Clouds on Greenland Coast.—In northeast Greenland the monumental investigations by Wegener furnish us with clearly defined results. In addition to full station weather observations collected for a period of two years at two neighboring stations—Pustervig, relatively near the inland-ice margin but within a canyon, and Danmarks-Haven, fifty miles further outward and upon the coast;[31] we have systematic observations with kites and captive balloons in ascents to heights generally of 1,500 meters and occasionally of 3,000 meters.[32] The results indicate that the larger weather disturbances are in the main controlled by the great high pressure area lying over the continent, that two strongly marked lower inversions in the atmosphere occur almost uniformly; the first within the lower 200 meters and explainable by surface radiation and latent heat of freezing and thawing, while the second lies between a thousand and fifteen hundred meters of altitude, at which level the great outward streaming from the inland-ice pours over the rock plateau to the westward of the station (average height of the plateau 800 meters). The most prevalent cloud form at the stations consists of a series of flat mushroom shapes in a succession of steps or stages located near the upper inversion level—on an average, 1,200 meters. These being clearly due to foehn conditions, they have by Wegener been given the name, "foehn clouds."

The twenty-three ascents of kites and balloons which were carried out at the time of more pronounced foehn, indicate that owing to the partial disappearance at such times of the lower cold moist layer, the temperature inversion of this lower layer is less pronounced and the temperature fall in the layers above it more pronounced, than at other times—in the most marked instances this fall

[31] A. Wegener, "Meteorologische Terminbeobachtungen am Danmarks-Haven, *Med om Grönland*, Vol. 42, 1911, pp. 124–355. W. Brand und A. Wegener, "Meteorologische Beobachtungen der Station Pustervig," ibid., 1912, pp. 446–562.

[32] A. Wegener, "Drachen- und Fesselballonaufstiege aus gefuhrt auf der Danmark-Expedition 1906–08," ibid., 1909, pp. 1–75.

is super-adiabatic. The typical foehn cloud layer at 1,200 meters is also at such times much more marked, and up to this level the wind velocity falls off with altitude. Of the greatest significance were the results of ascents made at the time of easterly winds—always light; since these show that the easterly winds fade away below the altitude of 1,000 meters, at which level they become replaced by the westerly winds which are controlled by the anti-cyclones.[33]

Areas of Relative Calm and of Air Highly Charged with Moisture Corresponding to the Central Plains Upon the Ice Domes.

Few Early Data.—At the time "Existing Glaciers" was published, no observational evidence bearing upon this point was available from either of the large continental glaciers, since neither had been penetrated to the central area. Nansen's crossing of Greenland within its narrowed southern portion, had revealed an area of calm near the divide on his section, but it could not then be predicated that this represented more than the margin of the central ice plain. The most valuable evidence then available was derived from Northeast Land (Spitzbergen), which is covered by a dome of inland-ice about a hundred and eightly miles in diameter and between two thousand three thousand feet in altitude in the central area. This area of inland-ice had in 1873 been penetrated by A. E. Nordenskiöld and Palander, who several times observed the simultaneous fall of irregular ice-grains enveloped in water and of small snow-flakes either rounded or star-like, the ice-grains freezing immediately on falling and becoming attached to the hair or clothes, since the air temperature was —4° to —5°.[34]

Recently Acquired Evidence from Antarctica.—During his penetration of the inland-ice area of Antarctica, Captain Amundsen entered near the 88th parallel, what he believed to be a region of permanent calm or of light winds and of generally clear weather. As evidence of this, the snow surface was smooth and with no in-

[33] A. Wegener, "Drachen- und Fesselballonaufstiege," *Med. om Grönl.*, Vol. 42, 1909, pp. 60–75.

[34] Cf. "Existing Glaciers," p. 277.

dication of drifting. To a depth of 2 meters no hard snow layers were encountered, so that the cutting of blocks (for guide cairns) was all but impossible. During the fortnight spent within this region the sky was clear with light winds, except on two days when there were snow flurries at intervals. The brightening after the snow was accompanied by such a high sun heat that even with most clothing removed the perspiration poured from the bodies of the men.[35]

Captain Scott, who entered the same general region about a month later, found conditions of atmosphere and snow which during the three weeks of his stay within it, agreed strikingly with those described by Amundsen. After passing the latitude 87½°, hardly a day passed that he did not jot down in his diary the fact of variable light winds and the noteworthy softness of the snow surface, several times expressing his opinion that the area is one of light winds. He was evidently puzzled by the appearance of the clouds, "which don't seem to come from anywhere, form and disperse without reason." Again he describes them as "coming and going overhead all day, drifting from the S. E., but constantly altering shape. Snow crystals falling all the time" (Vol. 1, p. 370). On January 19 on the return from the pole, he notes, "Snow clouds, looking very dense and spoiling the light, pass overhead from S., dropping very minute crystals; between showers the sun shows and the wind goes to the S. W."

Again and again he calls attention to the dampness and the chill in the air, so that when the temperature is observed, all are surprised that it is not lower. The sun was often shining through the snow mist, and bright sunlight and overcast sky interchanged with kaleidoscopic suddenness. Near the margins of this area snow blizzards were experienced, but in comparison with the Barrier blizzards Scott notes that the wind was surprisingly light. Temperatures rise after the blows. Within this central area the sastrugi are found in isolated areas, show cross directions and general lack of constancy. The snow got softer the farther they went to the southward, and it was soft below the surface also "as deep as you like to dig down." Yet with all the wind variations, there was evidently a preponderance of southerly and southeasterly winds. Like

[35] Roald Amundsen, "The South Pole," Vol. 2, Chapters XI.–XIII.

Amundsen, Scott noticed a slight descent toward the pole from latitude 89½°, which, taken in connection with Shackleton's observations, would indicate that a crest of the inland-ice lies to the westward of the routes.[36]

Recent Data from Greenland.—The account of de Quervain's transection of Greenland in 1912 in latitudes 66° to 70° N., affords strikingly similar pictures. Whereas for the first three weeks of the journey upon the inland-ice, or until the ascent had been made to the interior plain, the outward blowing winds had been so constant as to be depended upon in laying the course; shifting winds of light force were encountered upon the plateau, and when the grade had been reduced to 3″ of arc even west or northwest winds blew for short intervals. The air appeared to be strongly saturated with moisture, and at times only the heads of the party would be visible at moderate distances because of the bank of mist, and beards, chins, caps, etc., became frozen into solid masses of ice. Once over the divide, where the slope took on a descent of 8′ of arc, the wind blew strongly from the northwest.[37]

The expedition of Koch and Wegener which crossed Greenland in its widest section (in latitudes 71° to 79°), perhaps furnishes us with the most satisfactory evidence that has yet become available upon meteorological conditions above the central boss of a continental glacier; for the reason that no other expedition has penetrated so close to the heart of the area. From the preliminary report we learn that above the flat dome of the ice shield, an area of atmospheric calm was encountered and much mist, which in the morning was generally so dense as to hide the sun. The air was so supersaturated with moisture that the clothing was constantly wet and could be dried only occasionally and with much difficulty. Everywhere above the altitude of 2,000 meters the snow surface was granular and underlain by coarser grained material, though without hard separating crusts.[38]

Despite the supersaturation of the air and the frequent deposition of minute ice crystals from the clouds, it is pretty clear that if

[36] "Scott's Last Expedition," Vol. 1, pp. 363–383.

[37] A. de Quervain, "Quer durchs Grönlandeis," 1914, pp. 85–137.

[38] Alfred Wegener, "Vorläufiger Bericht über die wissenschaftlichen Ergebnisse der Expedition," *Zeitsch. d. Gesell. f. Erdk. z. Berlin*, 1914.

referred to the plateau surface, the peculiar shifting clouds so often observed by Scott and Amundsen are at a low level. The diurnal temperature chart published by de Quervain for his transection of Greenland, shows that radiation from the surface is apparently but little interfered with by clouds after the central plain has been reached. The abrupt change from this condition to one of small daily range of temperature, is found on both margins of the summit plain.

The Cirri Above and About the Existing Continental Glaciers.

The Earlier Data.—The relative abundance of cirrus and cirro-stratus clouds, not only above but about the margins of the continental glaciers, will be patent to any one who will read the lists of cloud observations which are published in the reports of the exploring expeditions.[39] In 1911 it was possible to cite the observation of Nansen, that during his crossing of the inland-ice though the sky was in the main clear, those clouds which were present were generally the cirri or some combination of these with cumuli or strati. From the Shackleton expedition in the Antarctic it was learned that the upper air currents near the winter station generally appeared to move in from the northwest quadrant and veer southerly as they advanced toward the pole. The "polar bands" or "Noah's Arc" clouds (cirro-strati) in general moved southerly, but to the west of the Ross Sea, the "polar bands" moved in from the north northeast or northeast veering round from the north. Thus, as a general rule, it would appear that in this region the upper currents carrying the cirri move roughly parallel to but in opposite direction from the stronger surface currents. In the same region additional evidence was derived from the behavior of the

[39] See, for example: "Wilkes Exploring Expedition (when off the Antarctic Continent)," Vol. XI., *Meteorology*, pp. 276–291; Mohn und Nansen, "Durchquerung von Grönland," *Pet. Mit.*, Ergänzungsh. 105, pp. 22–29; Duc d'Orleans, "Croisières océanographiques dans la mer du Gronland en 1905, Résultats Scientifiques," Bruxelles, 1907, pp. 52–67; Stade, "Grönland Expedition der Gesellschaft für Erdkunde," Vol. 2, pp. 417–441; Wegener, "Meteorologische Terminbeobachtungen," etc., *Med. om Grönland*, Vol. 42, 1911, pp. 202–311.

vapor cloud above Mt. Erebus, which starts from an elevation of nearly 14,000 feet.

Later Investigations.—In endeavoring to investigate further the movement of the cirri upon the borders of the inland-ice, the data supplied by the Greenland Expedition of the Berlin Geographical Society have been taken into consideration. Stade in his tabulated meteorological data at Station Karajak on the west coast, in some thirty-nine instances has supplied the direction of movement of the cirri observed. These I have plotted to form a wind-rose (Fig. 6),[40] which shows clearly the dominance of movements from the

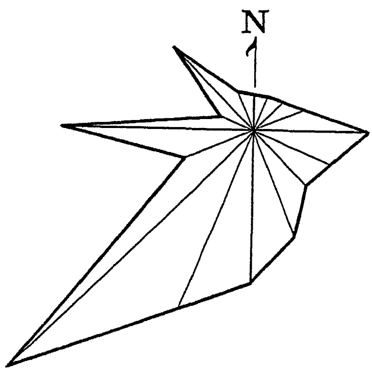


FIG. 6. Wind-rose for the cirri whose direction of motion was observed at station Karajac, West Greenland (several identified doubtfully as cirri are included).

southwest towards the northeast, or in other words in the general direction toward the interior region of the Greenland glacier.[41]

THE EVOLUTION OF THE GLACIAL BLIZZARD AND ITS ABRUPT TERMINATION IN FOEHN.

The Sequence of Events.—While there is apparently much in common between the Greenland and the Antarctic glacial blizzards,

[40] H. Stade, l. c., pp. 417–441.

[41] In central Europe Hesselberg has discovered a general correspondence between the drift of the cirri and that of the low pressure areas, but in view of the observations of de Quervain upon the stationary character of the depression over Baffin's Bay, it is unlikely that this conclusion can be applied to the borders of the inland-ice (Th. Hesselberg, "Ueber die Luftbewegung im Zirrusniveau und die Fortpflanzung der barometrischen Minima," *Beitr. z. Physik. d. fr Atmosphäre,* Vol. 5, 1913, pp. 198–205.

we are indebted especially to Professor David, the meteorologist of the Shackleton expedition, for a careful study of the Antarctic type of blizzard as observed by him at the winter station of the expedition. I shall here cite my earlier summary of the sequence of events with some personal interpretations.[42]

"The sequence of events during a blizzard begins with gentle northerly winds which continue for a day or two during which temperatures are low. David has suggested that during this time air is flowing south to take the place of air whose volume has been reduced as a result of the heat abstracted from it on the ice surface. Then there follow two or three days of absolute calm, during which the temperature continues to fall. Still further cooled upon the ice surface, the air, a week or more after the calm begins, starts to move outward in all directions and so develops (on the edge of the barrier) a southeasterly blizzard. Simultaneously with this movement the steam cap over the volcano of Erebus, which normally indicates an upper current from the northwest, swings round to the north and takes on an accelerated movement, as though it were being drawn from that direction to supply air to the void resulting from the violent surface current toward that direction. Corresponding to the increased velocity, the normal foehn effect near the pole must be much increased as it is also on the descent of the surface current from the plateau. As soon as the warming of the polar air from this cause has become general, the high air pressure of the central area is automatically reduced, and thus the blizzard gradually brings about its own extinction. To the warming effect of the descending air current there is rather suddenly added the latent heat of condensation of the moisture when it is precipitated in the form of fine ice crystals within the air layers just above the snow-ice surface. The rather sudden termination of the blizzard may be thus in part explained. David has suggested that a 'hydraulic ram effect' may be induced in the air of the upper currents, since the steam clouds over Erebus, normally the antitrades, are temporarily reversed in direction at the termination of a blizzard, and for a short interval blow northward."

Source of the Precipitated Snow.—The actual initiation of the strong wind may begin very suddenly, as has been especially emphasized by Simpson[43] and even more strikingly brought out by Mawson.[44] Referring to the source of the moisture of the blizzard as the cirri, I stated in 1911:

"There is, however, the probability that in general this snow or ice is adiabatically melted and vaporized during its descent to the plateau, and subsequently congealed as it mixes with the cold air above the plateau

[42] "Characteristics of Existing Glaciers," pp. 269–270.

[43] "Scott's Last Expedition," Vol. 2, p. 325.

[44] Mawson, "The Home of the Blizzard," Vol. 1, Chap. VII.

surface. This would explain the clear skies which are so general over both Greenland and Antarctica during snows in the higher levels. It is of course true that the latent heat of fusion and vaporization of ice, abstracted as it is from the air during its descent within the eye of the anticyclone, will counteract to some extent the warming adiabatic effect; and it is not improbable that the long duration of Antarctic blizzards and their somewhat sudden terminations accompanied by snowfall are explained in part by the transformations of latent and sensible heat.

"Additional evidence for the continental and glacial rather than the polar nature of the Antarctic anticyclone is derived from the strong blizzards observed at the British winter quarters on McMurdo Sound. *Whereas the lighter gales came from the southeast and indicated a control by local conditions, a blizzard of the first magnitude was not thus influenced, and always swept down from the southwest—that is, from the high plateau, and not from the pole, since otherwise the earth's rotation would have given it an easterly direction.* When its powers begin to wane, it is once more controlled by local conditions and the wind again comes from the southeasterly quarter."

Amundsen's Meteorological Records at Framheim.—Hardly less significant were the directions of prevailing winds observed at Framheim, the winter quarters of the Norwegian Antarctic expedition of 1910–12, when the position of the station is considered in reference to areas of inland-ice and shelf-ice. The great dome of inland-ice of King Edward Land lies to the eastward and southeastward distant only about 115 miles, whereas that of South Victoria Land and its extension to the southeastward, lies a number of times that distance away to the southwestward and westward. Now it was found that easterly winds predominated (31.9 per cent. of the time), with southwesterly and southerly winds next in order (14.3 per cent. and 12.3 per cent. respectively). Southeasterly winds were especially rare, and as calms reigned for a fifth of the time (21.3 per cent.), the winds for four fifths of the period are those accounted for. Earth rotation should deviate original southwesterly winds into a southerly direction, and southeasterly to easterly.[44a]

Alternations of Calm and Gale.—The strophic characteristic of the glacial blizzard thus involves frequent alternation of calms with strong gales, and all systematic observations about the inland-ice reveal this characteristic. As already pointed out, the strophic quality is to be expected from the recurring disturbance of balance and later recovery in opposing forces (ante, p. 188). Below in tabu-

[44a] R. Amundsen, "The South Pole," Vol. 2, pp. 381–382.

lar form are set forth the percentage of calm days to all others as determined at several stations near the margin of inland-ice:

Percentage of Calm Days to All Others.

	Per Cent.
Danmarks-Haven, Northeast Greenland[45]	26
Cape Adair, South Victoria Land[46]	45
Scott's First Base, South Victoria Land[47]	23
Cape Evans, South Victoria Land[48] (up to 4 miles per hr. 29.8 per cent.)	
Framheim, Whale's Bay[49] (up to 4 miles per hr. 42.2 per cent.)[48]	21.3

The Theory of Circum-Polar Whirls vs. the Glacial Anticyclones.

Views of Ferrel and Hann.—From a theoretical view-point, the theory of circumpolar whirls first enunciated by the American meteorologist Ferrel, has been a most serious obstacle in the way of securing a clear conception concerning the air circulation above continental glaciers. Ferrel's theory assumed that strong westerly winds sweep about the geographic poles with increasing acceleration of velocity and corresponding centrifugal effect, producing polar areas of calm and of low barometer. Of the southern polar region, Hann stated as late as 1897:[50]

> "The whole Antarctic circum-polar area presents us, as already stated, with a vast cyclone, of which the center is at the pole, while the westerly winds circulate round it."

This view was of course largely speculative, and when Bernacchi of the "Southern Cross" expedition had brought out on the basis of observations at Cape Adare the evidence for anticyclonic conditions over the south polar regions, Hann cautiously qualified his earlier statements in the following manner:

[45] Wegener, "Med. om Grönl.," Vol. 42, pp. 325–326.

[46] Bernacchi, in Borchgrevinck, "First on the Antarctic Continent," p. 306.

[47] Shaw, "National Antarctic Expedition, 1901–1904, Meteorol.," Pt. I., 1908.

[48] Simpson, "Scott's Last Expedition," Vol. 2, p. 320.

[49] Amundsen, "The South Pole," Vol. 2, pp. 381–382.

[50] "Handbuch der Klimatologie," 2te aufl., Vol. 3, 1897, p. 543.

"As regards the Antarctic Anticyclone, I have certainly not expressed myself quite clearly in my 'Klimatologie,' as you very fairly point out.

"It is certain that an area of pressure, which is higher than that of the surrounding area, lying over a chilled continent, or over any considerable land area, can coexist with a great polar cyclone, for instance, round the South Pole. The very low temperature can produce in the lower strata of the atmosphere a pressure higher than its environments. The anticyclone, however, must be very shallow, and at a moderate elevation the ordinary circulation of the atmosphere must reestablish itself. . . . It is just possible that further inland a slight increase of pressure might be observable. There is certainly no chance of the existence of a real continental anticyclone, inasmuch as at Cape Adare the barometer falls from summer to winter."[51]

The above and later qualified statements by Hann[52] fail to take proper recognition of the facts as known at the time, and in treatises on meteorology published within the last five years, the circum-polar whirls are still treated with slight qualifications of statement, and as though in harmony with observed facts.[53]

View of Meinardus.—Probably the fullest discussion of this subject is that of Meinardus in 1909, who is so firmly convinced that the anticyclonic conditions that were encoutered in Kaiser Wilhelm Land at the margin of the inland-ice, cannot have an upward extension beyond 2,000–3,000 meters, that he even prophesied for the interior portions of Antarctica a bare land area destitute of snow.[54] He says:

"The elevated parts of Antarctica above 2,000–3,000 meters extend into the great cyclone of the polar whirl and encounter westerly air currents during the entire year. With this verification, which also further can be supported by certain observations from the marginal region, there follows the conclusion *that the Antarctic anticyclone can in general be present as active element in the air circulation only in the lower parts of the South Polar region.* . . . At the sea level and on the borders of the inland-ice, that

[51] Letter written to Captain R. F. Scott in 1900, *The Antarctic Manual,* 1901, p. 34.

[52] "Lehrbuch der Meteorologie," 2te aufl., 1906, p. 345; Klimatologie, Vol. 1, 1908, p. 334.

[53] Moore, "Descriptive Meteorology," 1910, p. 141. Milham, "Meteorology," 1912, p. 162.

[54] W. Meinardus, "Meteorologische Ergebnisse der Winterstation der 'Gauss,' 1902–03, Deutsche Südpolar Expedition 1901–03," Vol. 3 (*Meteorol.,* I., Vol. 1), p. 332. (The italics are in the original, W. H. H.)

is, within the known coast areas, the anticyclonic conditions do not yet prevail."[55]

Referring to the observations by Captain Scott and by others upon the plateau back of the Admiralty Range in South Victoria Land, Meinardus is quick to seize upon the westerly winds which there prevail as evidence that the anticyclone has at these levels given place to the supposed overlying cyclones; failing utterly to note that the winds are here blowing directly down slope from the ice plateau—that is, radially.[56] Other statements in the report are likewise strikingly at variance with facts either known at the time or revealed by later exploration.

Objective Studies by Barkow in Antarctica.—The first opportunity to measure the upward extension of anticyclonic conditions over Antarctica, has been taken advantage of by Barkow, the meteorologist of the Second German Antarctic Expedition; who at the margin of the inland-ice of Prince Regent Luitpold Land (lat. 77° 45′ S., long. 34° 40′ W.) sent up pilot balloons, one on February 2, 1912, to the extreme elevation of 17,200 meters, or over 8 km. above the base of the stratosphere.[57] These observations disclose the fact that easterly and northeasterly winds prevailed at the time of observation in all levels *up to the ceiling of the troposphere,*[58] whereas with the beginning of the stratosphere, where at an elevation of 9,000 meters the wind turns suddenly through an angle of 180° and blows steadily from the southwest. If, as is probable, the margin of the continent corresponds to the margin of the inland-ice dome, these observations considered with due regard to the known deviation indicate an anticyclone fed by currents above the troposphere. Barkow calls attention to the speculations of Meinardus above referred to, and shows that they are controverted by the results of his observations.

[55] L. c., p. 333. Hardly in harmony with the facts known at the time, since easterly winds, and not westerly, are here the rule (cf. "Existing Glaciers," pp. 264–265, and ante, p. 197).

[56] L. c., p. 334.

[57] E. Barkow, "Vorläufiger Bericht über die meteorologischen Beobachtungen der deutschen antarktischen Expedition, 1911–12," *Ver. d. k. preuss. meteor. Inst.*, No. 265 (Abh., Vol. 4, No. 11), Berlin, 1913, pp. 7–11.

[58] The italics are mine.—W. H. H.

Barkow also carried out kite and balloon ascents, of which a proportionately slight per cent. only failed to show strong inversions of the lower atmosphere, these inversions being proportionately both strong and frequent during the winter season. The entire lower layer of 2,000 meters height was shown to have an average higher temperature than the lowermost layer, the temperature rise from the bottom being often as much as 10° C., and in one instance 19.5° C. In the spring season an alternation of inversions (Blätterstruktur) was observed.

De Quervain's Studies in Southwest Greenland.—No less decisive in showing the absence of polar whirls are conclusions to be drawn from observations on the borders of the inland-ice of Greenland. At a number of stations on the west and southwest coasts ranging between latitudes 64° and 69°, de Quervain and Stolberg in 1909 conducted ascents of pilot balloons during the spring and early summer, carrying their observations to extreme heights often in excess of 10,000 meters (6⅔ miles),[59] and in one instance of 16,000 meters. In 1912 Drs. Jost and Stolberg supplemented these observations by a second series carried out through the winter season, with results concerning which only a preliminary statement is as yet available.[60]

As has already been explained, the prevailing surface currents at these stations are controlled by the Greenland anticyclones and blow from the southeasterly quadrant, though with considerable modification by local conditions below the level of 1,000 meters. On the basis of his balloon observations, de Quervain has declared that "at least in greater elevations a polar whirl which is in any degree unified and connects the different low pressure regions of the circumpolar latitudes, can, for the time of our observations in Greenland and Iceland, not be thought of." This conclusion was later extended to the remaining portion of the year, as clearly stated in the preliminary announcement of the results of the later series of observations.

[59] A. de Quervain, "Gleichzeitige Pilotaufstiege in Westgrönland und Island, Veranstaltet durch die schweizerisch-deutschen Grönland-expedition und das danische meteorologische Institut," *Beitr. z. Physik d. fr. Atmosphäre,* Vol. 5, 1913, pp. 132–158.

[60] A. de Quervain, "Quer durchs Gronlandeis, Die schweizerische Grönland-Expedition 1912–13," Munich, 1914, pp. 196, pls. 15, figs. 37 and map.

Distribution of Air Circulation in Successive Levels at the Inland-Ice Margin.—De Quervain's data upon wind direction are so vitally important as to merit some further consideration, particularly as regards the distribution of circulation within the different levels; and I have therefore used them to plot the wind-roses for each of the following ranges of altitude: 0–1,000 meters, 1,000–3,000 m., 3,000–5,000 m. (also separately 3,000–4,000 m. and 4,000–

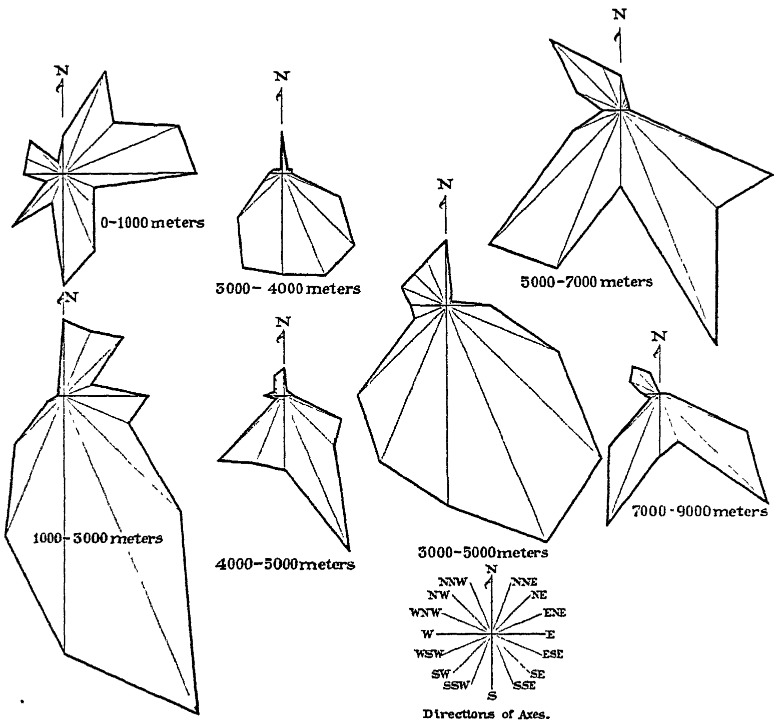


FIG. 7. Wind-roses to illustrate the prevailing winds between the levels indicated at stations on the west and southwest coast of Greenland (from data by de Quervain).

5,000 m,), 5,000–7,000 m., 7,000–9,000 m., and 9,000–11,000 m. For the lower levels between 40 and 58 ascents were available, whereas above 9,000 meters there were 13 and less. The wind-roses have been plotted with weighting for wind force (5 m.p.s. counting as one unit and the nearest unit being taken). Wind

velocities less than 5 m.p.s. were disregarded. The results, which are set forth in Fig. 7, show that below an altitude of 1,000 meters the wind, usually of low velocity, is notably variable and controlled by local conditions. At the level of 1,000 meters the outward flowing currents make their appearance in force and control the circulation up to an altitude of between four and five kilometers, above which level inward blowing currents from the southwesterly quadrant are of equal frequency and of about the same force as the outward blowing currents from the southeast. The clockwise deviation of currents in the anticyclone lead us to suppose that the outward blowing currents start from the interior in a more easterly direction, and that the inward blowing currents from the southwest are almost directly opposed, when they arrive in the interior.

The observations of Wegener made with kites and captive balloons in northeast Greenland, were not generally carried above an altitude of 2,000 meters, though in a few instances considerably higher. They agree among themselves and with those from west Greenland, in showing the presence of relatively variable winds up to about a thousand meters altitude, where these currents are replaced by the strong winds coming down the slope of the inland-ice and increasing in force and in clockwise deviation as one ascends to the limits of the observations. While they are therefore of great interest in revealing the strength and the upward extension of the glacial anticyclone, they have less direct bearing upon the question of circumpolar whirls.[61]

With the above data of Barkow and de Quervain before us, it seems that the time has arrived for laying the specter of the circumpolar whirl, and of returning to an objective basis of reasoning.

Winds About the Margin of the Inland-Ice as a Measure of the Vigor of the Antarctic Anticyclone.

The Zone of Control off "Wilkes Land."—The vigor of a glacial anticyclone may be measured, upon the one hand, by its extension upward from the glacier surface, as has been considered in the last section. Upon the other hand, it may be possible to use the exten-

[61] Wegener, "Drachen- und Fesselballonaufstiege," etc., pp. 55–59.

sion of its circulation outward beyond the glacier margin as an independent measure of its energy. This latter line of inquiry is a particularly fruitful one, for hitherto there has been a general tendency to delimit the zones of wind within the Southern ocean in terms of parallels of latitude.[62] Some years ago under the strong impression that the vigor of the Antarctic anticyclone should dominate within an extra-marginal zone upon the sea, I plotted the wind observations regularly made by the Wilkes Exploring Expedition;[63]

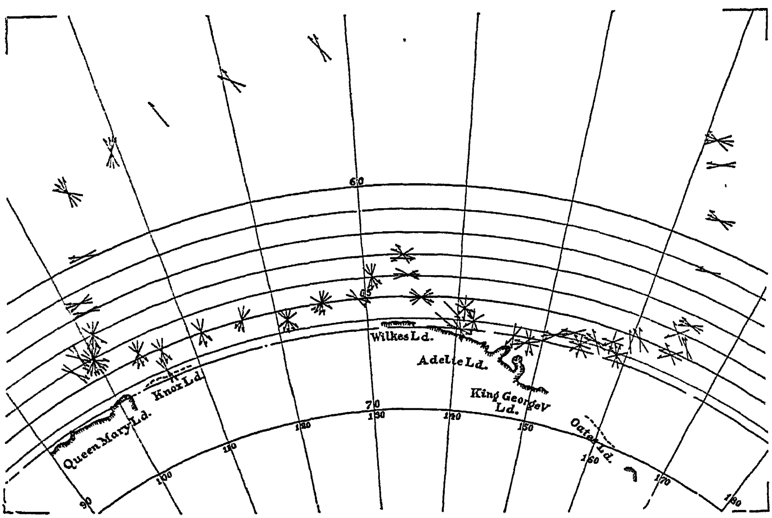


FIG. 8. Map of a portion of Antarctica on which the wind directions recorded by the Wilkes Exploring Expedition have been plotted, but with the margins of the continent corrected so as to accord with Mawson's map. *The arrows point to the wind quarter.*

but was puzzled to find that, whereas there was evident control by the anticyclone within a zone several degrees in width for all points to the westward of long. 150° E., this did not hold for the eastern portion of the route. Now that Mawson has definitely shown[64] Wilkes to have been in error in locating the margin of the continent for that portion of his route to the eastward of longitude 150° E., the apparent lack of harmony which I encountered is suffi-

[62] Cf., for example, Meinardus, l. c.

[63] "Wilkes's Exploring Expedition," Vol. II (Meteorology), pp. 272–296.

[64] *Geogr. Jour.*, Vol. 44 (September, 1914), pp. 257–286.

ciently explained. As will be readily seen by reference to Fig. 8, wherever Wilkes was within about three degrees, or some 200 miles, of the inland-ice, the prevailing westerly winds were replaced by southerly and southeasterly ones blowing off the ice. Mawson's own observations leave us in no doubt whatever that this rule of control holds for those margins of the continent which he explored to the eastward of longitude 150° E.

So apparent is the zone of control limited to a belt of 200 miles breadth, at the time of year when Wilkes made his observations, that the winds within and those without this zone for several degrees further, have been plotted in separate roses with results shown in Fig. 9.

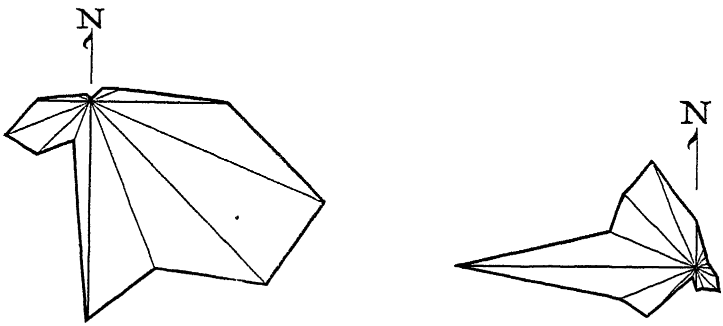


FIG. 9. At the left; wind-rose based upon Wilkes's observations at points distant less than 200 miles from the inland-ice; and, at the right; wind-rose for a zone several degrees in width lying immediately outside the zone of control.

Capt. Davis of the Australian Antarctic Expedition cites an interesting incident in the voyage of the *Aurora* off "Wilkes Land" which indicates he was at the margin of the zone of control.[64a]

The wind observations made by the "Challenger Expedition" at points which we now know to have been near the inland-ice,[65] are confirmation of this conclusion that the effect of the anticyclone extends outward from the margins. Had the observations been

[64a] Home of the Blizzard, vol. 2, p. 40.

[65] Challenger Reports, Summary of Results, First part, chart 23.

those of the first German expedition in 1901–03,[66] offer valuable

[66] W. Meinardus, "Deutsche Südpol-Expedition 1901–03," Vol. 4 (Meteor., Vol. 2), pp. 312–319.

taken in the winter season, it is well nigh certain that the zone of control would have been found much wider.

Effect of the Greenland Anticyclone Upon Migrating Cyclonic Depressions.

Supposed Passage of Cyclones Across the Continental Glacier of Greenland.—A question which has been raised in connection with the Greenland continental glacier concerns the interaction of the glacial anticyclone and the migrating cyclones which have been supposed to move in toward the continent. Upon this assumption it might be held, upon the one hand, that the cyclone temporarily overwhelms the anticyclone, and "springing over it" continues upon its course; or, upon the other, that the cyclone is extinguished by the greater vigor of the anticyclone. Evidence which is now fast accumulating shows that, if the cyclones really advance toward the anticyclone, they are at least halted at its margin, and that both become parts of a system of exchanges planetary in its scope. There is, however, upon the assumption stated the possibility that an especially vigorous cyclone in approaching the Greenland coast during one of the weaker stages in the anticyclonic strophe, may make its influence felt not only upon the near side of the anticyclone but beyond it as well.

Nansen's Observations.—Nansen's conclusion after his crossing of Greenland was, that "the plateau seems to be too high and the air too cold to allow depressions or storm centers to pass across, though, nevertheless, our observations show that in several instances the depressions of Baffin's Bay, Davis Strait and Denmark Strait can make themselves felt in the very interior. We experienced, also, one instance of the crossing of a depression in the storm center which passed over us on September 8. This must have been, according to Professor Mohn, a secondary depression which lay over Baffin's Bay some days before."[67] This was, however, in latitude 64° where the inland-ice is extended southward in a relatively narrow tongue. According to de Quervain on but one occasion during the period of his observations on the Greenland west

[67] "First Crossing of Greenland," Vol. 2, p. 496.

coast, was there "an approximation to establishing" a relationship between an extremely rare northwest wind in the upper levels and a deep low area which lay over the Greenland Sea.[68]

The High Pressure Storms and the "Tauben" Depressions Registered at Danmarks-Haven.—In connection with the series of continuous meteorological observations made at Danmarks-Haven in northeast Greenland, Wegener found that while low pressure areas of normal character arrived at the station, they appeared to proceed from the area of the Greenland Sea; and in the absence of parallel observations, he assumed from the southward. The great storms came with an expansion of the high pressure area lying above the continent—so-called "high pressure storms." During the two years over which the observations extended, there passed over the station on two occasions (October and January), what Wegener has called "tauben"[69] depressions. On these occasions the barometer took a deep plunge with reverse movement, as it does during the passage of a tropical cyclone; yet there resulted neither precipitation of any kind nor any wind worthy of mention. This rather remarkable phenomenon Wegener has sought to explain as due to a cyclonic movement which has "sprung over" the anticyclone above the inland-ice, and in so doing has been robbed of its moisture,[70] and also, it would seem, of its circulation.

In view of all the facts, there is reason to doubt that "low" areas ever get across the larger domes of inland-ice; and the storm paths which Vincent has drawn across the continent of Greenland as though it were an expanse of ocean, should be accorded little weight, though it would seem that Wegener has been somewhat influenced by them.[71]

[68] De Quervain, "Gleichzeitige Pilotballonaufstiege, etc.," p. 146.

[69] Perhaps best translated, "barren," or "sterile."

[70] A. Wegener, "Meteorol. Terminbeob. am Danmarks-Haven," pp. 328, 332–334.

[71] E. Vincent, "Sur la marche des minima barométriques dans la région polaire arctique, du mois de septembre 1882 au mois d'août 1883," *Mem. de l'acad. Roy. de Belgique,* 1910.

The Fixed Low Pressure Areas Marginal to the Inland-Ice Masses.

Antarctica.—The Filchner expedition seems to have established the fact that a fixed cyclonic depression lies off the border of the Antarctic continent covering the indentation of the Weddell Sea.[72] In the light of this discovery it now seems highly probably that a similar fixed depression lies above the indentation of the Ross Sea on the other side of the Antarctic regions and in nearly similar relationship to the inland-ice on either side.[73]

Greenland.—It is well known that a fixed low which is especially marked in the winter season lies off the southeast coast of Greenland, usually assumed to wrap itself about Cape Farewell in the form of a crescent, and extends northward into Davis Straits.[74] Recent studies of the free atmosphere by de Quervain at various points on the west and southwest coasts of Greenland indicate that a stationary area of low barometer (probably continuous with this) extends northward in Baffin's Bay as far at least as Disco Island.[75] The simultaneous studies carried out with pilot balloons at Akureyri in Iceland, indicate clearly that a stationary depression lies over the Greenland Sea to the northward of Iceland and between the Greenland and Norwegian coasts.[76] The Danes from the journeys of bottles set adrift during the expedition of 1906–08, determined that the currents within this sea are such as would indicate a stationary cyclone, since movements were southward along but off the Greenland coast until near the latitude of Iceland, where they are deflected eastward and later northward so as to follow the trend of the Norwegian coast.[77] Thus about both the glacial anticyclone

[72] L. c.

[73] See R. F. Scott, "Voyage of the *Discovery*," Vol. 2, p. 412; L. Bernacchi, "To the South Polar Regions, 1901," p. 298; W. S. Bruce, "Polar Explorations," New York, 1911, p. 187; Simpson, "Scott's Last Expedition," Vol. 2, p. 324.

[74] Cf., for example, Berghaus, "Atlas der Meteorologie," Pls. 33–34.

[75] A. de Quervain, "Gleichzeitige Pilotballonaufstiege in Westgrönland und Island," *Beiträge z. Physik. de Freien Atmosphäre,* Vol. 5, 1913, p. 145.

[76] de Quervain, l. c., p. 146.

[77] Alf. Trolle, "Danmark-Ekspeditionen til Gronlands Nordostkyst, 1906–08, under ledelse af L. Mylius-Erichsen," *Med. om Gronl.,* Vol. 41, 1913. See also, Sir John Murray and Dr. J. Hjort, "The Depths of the Ocean," London, 1912, p. 284.

groups it would now appear that the stationary "lows" are located where land barriers oppose a progressive movement.

The Rôle of the Glacial Anticyclones of High Latitudes in the General Air Circulation.

Circulation is Through Cyclones and Anticyclones, Not Merely Within Them.—In an earlier section it has been shown how the preconceived notion of a polar cyclone, the circumpolar whirl, has held back the advance of knowledge where the polar regions are concerned; and how this theory has now been effectually disposed of by the observations of de Quervain, Stolberg, Barkow and others.

The progressing cyclones within the atmosphere were by Ferrel assumed to be symmetrical in their distribution, with warm upward-moving central portions and cold marginal rims; to circulate the same body of air which repeatedly passes through certain paths; and to have their origin in areas of excessive local insolation. Instead of being symmetrical, as has now so generally been assumed, the study of isotherms in connection with cyclones has shown that these lines usually trend in the United States from southwest to northeast, crossing the cyclone by quite regular paths instead of being circular about its center. The evidence derived from international cloud observations would seem to show that the cyclone is a form of circulation *through which fresh portions of the atmosphere continue to stream;* and both cyclones and anticyclones are to be regarded as eddies which at the surface of the earth have each a hot and a cold side. The same air streams through both, its progress when projected upon the earth's surface being a sinuous line.

Belts of Progressing Cyclones and Anticyclones about the Antarctic Glacial Anticyclones.—The southern hemisphere, being less invaded by the continents, offers for the purposes of study some advantages on the side of relative simplicity, and it has in its meteorological aspects been recently comprehensively treated by Lockyer,[78] who has taken full account of the results of Antarctic

[78] W. J. S. Lockyer, "Southern Hemisphere Surface Air Circulation," etc., Solar Physics Committee under direction of Sir Norman Lockyer, London, 1910, pp. 109, pls. 15.

explorations and has endeavored to show the conjugate relationship of the Antarctic anticyclone area with successive zones of cyclones and anticyclones which migrate in an easterly direction around it. Thus it is found that between the low pressure zones lying within the tropics, and the fixed high pressure area above Antarctica, there are centered near the latitude of 40° S., a series of broad anticyclones which progress eastwardly and produce the effect of a zone of mean high pressure.[79] To the southward of this series of anticyclones and centered near the latitude of 60° S., there are a series of more vigorous cyclones of smaller diameter but progressing eastwardly at about the same angular rate. As we now know from later observations, the stationary cyclones lying over the Weddell and Ross Seas, establish further connection with the anticyclones above the Antarctic continent.

The cold outward flowing currents from the Antarctic continent upon reaching the zones of progressing cyclones are believed by Lockyer to ascend in them upon the west side, thus accounting for the cold western half of these cyclones near the ocean level.

The Australian Antarctic Expedition appears now to have supplied the evidence for such a rise of the air at the southern margin of the progressing cyclones near the borders of Adelie Land. As Mawson puts it:

> "It appeared as if we were situated on the battlefield, so to speak, of opposing forces. The pacific influence of the 'north' would hold sway for a few hours, a whole day, or even for a few days. Then the vast energies of the 'south' would rise to the bursting point and a 'through blizzard' would be the result."

At this junction zone of the glacial anticyclone with progressing cyclones, the air rises to produce rotating cumulus clouds, and it seems not unlikely that the interesting "whirlies" are connected with this uprise.[80]

The air having ascended in a cyclone on its journey northward toward the equator is believed next to pass downward through the progressing anticyclones to the northward, and to reach the ocean's surface as the warm current on the west side of these eddies.

[79] W. J. Humphreys, "On the Physics of the Atmosphere," *Jour. Franklin Inst.*, 1913, pp. 222–223.

[80] Mawson, "The Home of the Blizzard," Vol. 2, pp. 157–8 (fig.).

Mawson's demonstration through wireless communications that the hurricanes of Adelie Land preceded by some 48 hours the arrival of storms at the Australian south coast, would seem to support strongly this view (Fig. 10).[81]

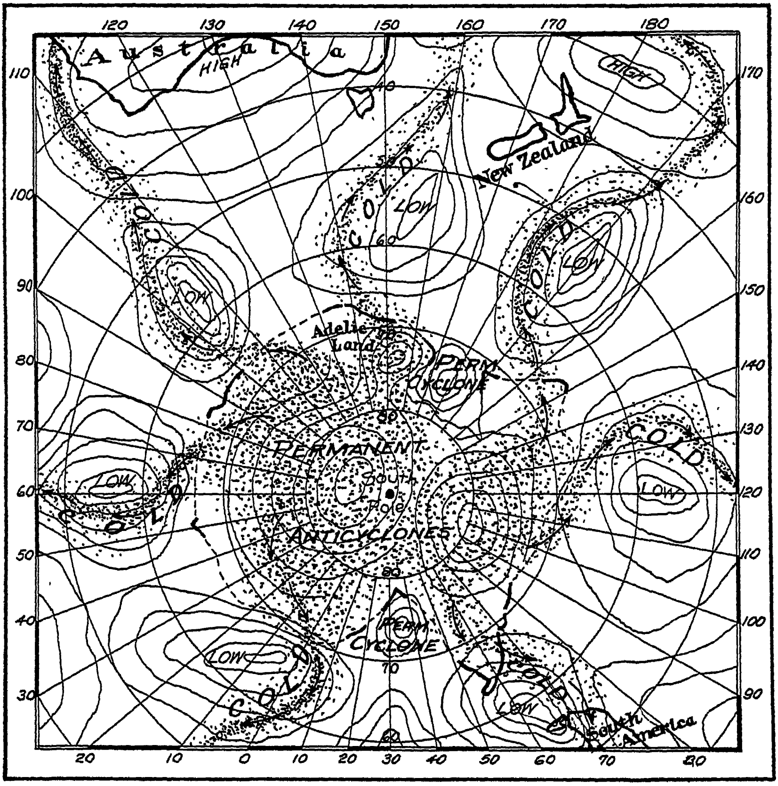
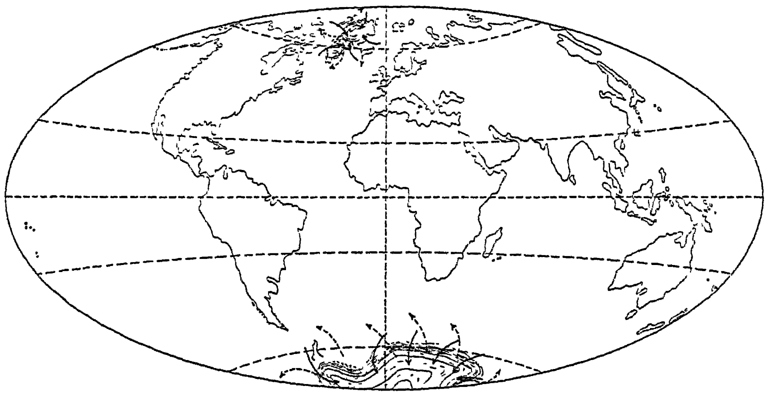


FIG. 10. Map to illustrate the prevailing atmospheric conditions to the southward of Australia (compiled from maps by Lockyer and Mawson).

The Rôle of the Glacial Anticyclones in the General Air Circulation to Draw Down the Air of the Upper Stratum in the Troposphere and to Direct it Equatorward.—From these geographical relationships it appears highly probable that the glacial anticyclones above the inland-ice masses stand in a definite conjugate relationship to stationary cyclones above embayments of the continent.

[81] Cf., also, "The Home of the Blizzard," Vol. 2, fig. opp. p. 141.

The glacial anticyclones of Greenland and Antarctica through drawing down of air from the upper levels and as a consequence of a throughout centrifugal surface circulation, are a very important factor in reversing the high poleward currents within high latitudes and directing them equatorward. The source of energy which



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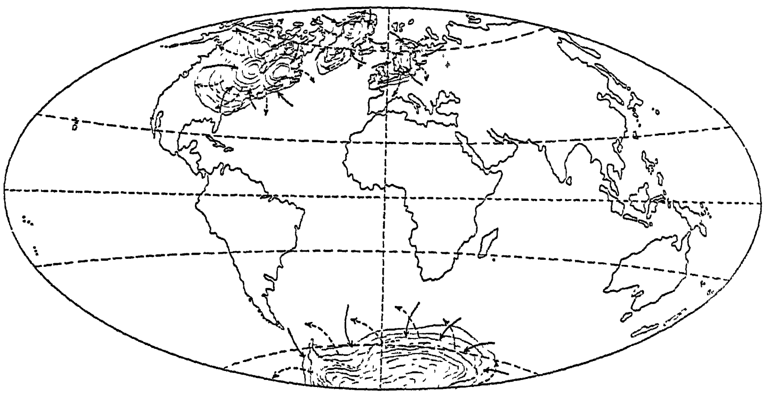

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FIG. 11. (*a*) World map to show the present position of the earth's wind poles where the air of the upper stratum within the troposphere is in large part returned to the surface in glacial anticyclones. (*b*) World map to show the corresponding wind poles of the Pleistocene period.

maintains the whole system in motion, is of course the sun's heat concentrated within the tropics and in large measure absorbed over the continental glaciers (Fig. 11a). It is to be assumed that the

uplands of northeastern Siberia, the smaller masses of inland-ice within the Arctic region, and in fact any area where heat radiation is large, contribute in lesser measure to draw down the upper air currents and reverse their direction. It is the unhindered radiation of desert areas which is responsible for the anticyclonic conditions over them in the winter season. Abnormally high insolation in the summer season may, however, overbalance this effect and produce cyclonic effects. The moisture locked up in the ice needles of the cirri and related cloud forms above those areas of ocean where evaporation is large, is thus returned to the earth and especially within the glacial anticyclones. Of this moisture a portion is added to the glacier mass, but at the present time a much larger portion is blown off the glacier surface into the sea and so returned to its source in the waters of the ocean.

University of Michigan,
Ann Arbor,
March 12, 1915.

THE TEST OF A PURE SPECIES OF ŒNOTHERA.[1]

By BRADLEY MOORE DAVIS.

(*Read April 23, 1915.*)

There is probably no group of plants the genetic behavior of which has received so much study as the species of *Œnothera.* No group of plants is more prominently before the attention of experimental plant morphologists, and yet to many botanists it may appear that no group has yielded less of satisfaction. Among the workers with these forms there is the widest divergence of opinion, and of general conclusions there is little to show for the time that has passed since the appearance of "Die Mutationstheorie" in 1901 and the many years of study that De Vries devoted to the group previous to this date.

Can we find the point around which the difficulties cluster most thickly or from which the varied interpretations diverge most sharply? And, finding such a point can we formulate lines of experimentation that may clear the confusion of assumptions from which the various workers have proceeded to follow the lines of study that seemed to them to lead towards the light? To the writer the center of the difficulties lies in the fact that we have no accepted tests for the genetic purity of an *Œnothera* species.

By the genetic purity of a species we mean such a constitution of the germ plasm that a form is able to produce gametes of one type only for each sex. That is to say all male gametes of the form should have the same germinal constitution and thus be physiologically and morphologically equivalent, and all female gametes likewise should be of the same type. The male and female gametes may, however, differ in their respective effects upon the characters of a succeeding generation as shown by the marked differences exhibited by certain reciprocal crosses, for example, the reciprocals between *biennis* and *muricata,* or between *biennis* and *franciscana*

[1] Genetical Studies on Œnothera—VI.

(De Vries '13, Davis '14). The zygotes of a pure species must be uniform since the gametes of each sex are respectively similar, and a pure species, to employ that convenient expression of Bateson's, is therefore homozygous.

It has generally been held that no further proof of the genetic purity of a species is necessary than the established fact that it will "breed true," and I venture to believe that at present most workers among the œnotheras regard this test as entirely sufficient to establish the character of any material with which they work. If any line of *Œnothera* breeds true in large cultures it is confidently regarded as homozygous. Should a line fail to breed true to any considerable degree it is stamped as a hybrid if the investigator inclines towards the methods of analysis characteristic of the Mendelian school. Those who believe in mutations are so fully content with this test that to them a form need breed only reasonably true to pass as a pure species and the departures from the type, called mutations, are interpreted as due to modifications of the germ plasm not, however, the result of hybridism.

If a line of *Œnothera* fails to breed true to a very considerable degree and thus becomes suspected of a hybrid constitution, few workers would think of using it as favorable material for experimental studies to test the mutation theory. It is the lines which breed reasonably true that chiefly form the subjects of *Œnothera* discussions with reference to the theory of mutation. Such a line is the *Lamarckiana* of De Vries's cultures which when grown in large numbers in selfed families appears uniform except for certain small proportions of individuals, "mutants," which stand out clearly from the mass with distinctive characters that are readily recognized and may be clearly described. It is important to note that these new types are not connected by intergrading forms with the parent *Lamarckiana* and that they appear in successive generations of *Lamarckiana* with certain degrees of regularity.

More impressive than this history of *Lamarckiana* which has flowers open-pollinated, and consequently likely in Nature to have been crossed by insects, is the behavior reported for certain lines of *Œnothera* with flowers close-pollinated in the bud, a condition that obviously gives their own pollen the first chance to function and

thus greatly reduces the probabilities of cross-pollination. Such a plant is the *biennis* of Holland and other parts of Europe, a type of especial interest not only for its clear morphological characters but also because there is good reason for believing the line to be very old. This plant forms a large population in Holland with no near relatives and must have lived there for many years to have so thoroughly established itself. Indeed it seems probable that this *Œnothera,* the Dutch *biennis,* has come down to us essentially unchanged from the times of Linnæus who gave us its name. We know of no plant better representative of a species of *Œnothera* and we know of no *Œnothera* which better satisfies the generally accepted requirement that a species should "breed true."

Œnothera biennis L. in large cultures comes so true that hundreds of plants may be grown without finding a single departure from the type. Yet Stomps ('14) in large cultures of selfed lines from a single wild plant collected in 1905 discovered that this Dutch *biennis* throws occasional marked variants ("mutants") and he described a *biennis semi-gigas* with the triploid number of chromosomes (21), a dwarf type *biennis nanella,* and a color variety *biennis sulfurea* with pale yellow petals. De Vries ('15) at once took up the study of certain of the lines established by Stomps and grew cultures which totaled 8,500 plants. Among these were 4 plants of *biennis semi-gigas* about 0.05 per cent., 8 plants of *biennis nanella* about 0.1 per cent., and 27 plants of *biennis sulfurea* about 0.3 per cent. Since the percentages from *Lamarckiana* are for *semi-gigas* 0.3 per cent. and for nanella 1 to 2 per cent. it should be noted that with respect to these "mutants" *biennis* appears to be the more stable of the two species, although the color variety *biennis sulfurea* constitutes a new type of variant in experimental studies on œnotheras. A culture of over 1,000 plants from selfed seed of *biennis sulfurea,* all with pale yellow flowers, produced 2 dwarfs thus establishing a "double mutant" *O. biennis* mut. *sulfurea* mut. *nanella.*

As evidence for the mutation theory of De Vries this behavior of the Dutch *biennis* is to the writer much more trustworthy evidence than the behavior of *Lamarckiana* for the reason that the latter plant in his opinion does not have a clear record of long

existence, and probably is a form of comparatively recent origin. De Vries ('15, p. 173) has asserted again most vigorously his belief that *Lamarckiana* may be identified with a specimen from the United States collected by Michaux and now in the collections of the Museum d'Histoire Naturelle in Paris (De Vries, '14). With this view I cannot accord for reasons recently published (Davis, '15*a*). The showing of "mutants" from *Œnothera biennis* can hardly be considered very encouraging for the mutation theory of organic evolution when it is remembered that *biennis semi-gigas* is self sterile, that *biennis nanella* is frequently weakly or diseased, and that *biennis sulfurea* is clearly a retrogressive type having lost the power of producing normal yellow flowers.

Although *O. biennis* of all the œnotheras brought into the experimental garden still seems to me the form most free from suspicion of gametic impurity, nevertheless the line of Stomps has not, so far as we know, been subjected to the tests of a pure species summarized at the conclusion of this paper. De Vries ('15, p. 173) is mistaken in quoting me as conceding for this species a pure origin. I regard it simply as the safest material yet known on which to conduct studies in mutation, and with which other forms may be crossed to determine by the constitution of the F_1 hybrid generation whether or not their gametes are uniform. If in such a breeding test the F_1 progeny fall into two or more classes the assumption is justified that the form crossed with *biennis* must produce different classes of gametes. If the F_1 hybrid generation is uniform then it is clear that the functioning gametes male and female are respectively uniform. The fact that *Lamarckiana* crossed with *biennis* produces the "twin hybrids" *laeta* and *velutina* is, as has frequently been pointed out, one of the most important facts favoring the hybrid nature of *Lamarckiana*. It seems to me not improbable that other species of *Œnothera* will eventually be isolated more stable than the Dutch *biennis*.

Some exceedingly interesting observations have recently been reported by Bartlett ('15 *a, b, c*) on the behavior of certain small-flowered, self-pollinated American œnotheras. When grown in selfed lines these forms exhibit a behavior similar to that of *Lamarckiana* and *biennis* in throwing off in successive generations

certain new types. Thus from one of the species, *Œnothera stenomeres,* a mutant *gigas* appeared with the diploid number of chromosomes, and from another species, *O. Reynoldsii,* certain individuals throw from 60 per cent. to 80 per cent. of dwarfs. It is too early to discuss the remarkable peculiarities of these forms since the material of Bartlett has not yet been tested for its purity along the lines presently to be discussed. Bartlett regards the new types as "mutants" in the sense of De Vries. The important point for our consideration at present is the fact that these wild plants apparently continue to reproduce themselves from generation to generation even while giving rise to the new forms.

With respect to the taxonomic status of the plants which we have just considered the writer sees no alternative but their recognition as clear species. The *Lamarckiana* of De Vries, the *biennis* of Linnæus, and most of the types which Bartlett has segregated from the American wild œnotheras breed true as to the mass of their progeny. What further qualifications can taxonomy in reason demand? Species they are by virtue of their morphology and by the test of the experimental garden which shows their characters to be stable to an extent that renders it certain that each line self-pollinated will maintain itself unchanged, indefinitely as far as we can see, through successive generations.

The argument that will follow as to the genetic constitution of these species of *Œnothera* does not in the least affect the matter of their recognition in taxonomy as species. It may be prefaced by two questions stated as follows: Are the types pure species, homozygous because the plants develop male gametes of one type only and because their female gametes have a uniform germinal constitution? Or, are the types heterozygous developing different types of male gametes and different types of female; briefly expressed have they in some degree a hybrid constitution?

But it will at once be asked, how can a species be hybrid even to a small degree and yet breed as true as do these forms under consideration? Where in their behavior is evidence of a hybrid constitution such as might appear in the splitting off of numerous different forms varying from the parent type, some in small degrees and some in larger degrees? Where is evidence of an orderly segre-

gation of characters such as has been demonstrated by the Mendelian research of recent years? To these questions it must frankly be answered that only here and there are glimpses of situations which may possibly be interpreted in terms of Mendelian analysis. For example the characters of the "mutants" are frequently clearly retrogressive which indicates that gametes are formed lacking certain factors and suggests phenomena characteristic of segregation from heterozygous stock and very common in Mendelian behavior. Again, the repetition of the same "mutants" in a series of generations suggests a mechanism of precision such as we have come to associate with Mendelian inheritance. It is not, however, my purpose to argue at present this phase of the discussion for the experimental data before us is not in such shape that it can be handled to the best advantage. We admit that the "mutants" themselves do not establish their parents as in their nature hybrids. If they did there would of course be no discussion.

Under two conditions and apparently two only can a heterozygous species be conceived as breeding true.

First, if of the varied possible types of gametes *only such unite and produce fertile zygotes as will perpetuate the same germinal constitution as the parent,* then from such zygotes a heterozygous line might continue indefinitely as an impure or hybrid species. Under such conditions gametes which might in varied combinations give a series of different forms (segregates) are either not matured or if matured fail to function. Some degree of pollen and ovule sterility must be expected as the result of such conditions.

Second, if of a varied assortment of zygotes formed by the union of different types of gametes, *only those develop which have the germinal constitution of the parent* then again a heterozygous line might continue indefinitely and constitute a species, although impure or hybrid in its nature. Since all of the zygotes which result from other combinations of gametes either die or fail to develop beyond some early stage in the life history this condition would result in some degree of seed sterility or in the production of weak plants that must soon perish.

Now the œnotheras as a group exhibit a very remarkable amount of pollen sterility and also a high degree of ovule abortion, and

these plants frequently give extraordinarily low yields of fertile seeds although seed-like structures may be formed in abundance. These facts we are just beginning to appreciate as offering problems for study. They seem to the writer of vital importance to the discussion of *Œnothera* genetics, facts which the Mutationists cannot ignore and behind which the Mendelians can maintain at present a very strong defence for their interpretations of the peculiarities of *Œnothera* behavior.

With respect to pollen sterility it has for many years been known that *Lamarckiana* and other species of *Œnothera* present large proportions of abortive pollen grains. Bateson (1902) early seized on the point and suggested that the high degree of pollen abortion in *Lamarckiana* indicated a hybrid plant exhibiting partial sterility. Geerts ('09) in an excellent account of the cytology of *Lamarckina* showed that approximately one half of the pollen grains fail to mature and that one half of the ovules fail to develop embryo sacs. Geerts ('09, p. 89) also made an examination of more than one hundred species of the Onagraceæ, giving us the conditions of pollen and ovulue fertility represented in some fifteen genera. He found generally in species of *Œnothera* and allied genera a degree of sterility similar to that in *Œnothera Lamarckiana,* about 50 per cent. for both pollen and ovules. On the other hand certain species of *Jussieua, Zauschneria, Epilobium, Boisduvalia* and *Lopezia* are wholly or almost wholly fertile.

My own examination of conditions in the material of *Œnothera* with which in recent years I have worked has shown some remarkable differences in the amount of pollen and seed sterility. Such close pollinated types as the Dutch *biennis,* the Dutch *muricata,* American *muricata* (from Woods Hole), *Tracyi,* and a number of American small-flowered species (for example *biennis* A and *biennis* D of my cultures (Davis, '11, p. 197 and '12, p. 385)), have very large amounts of sterile pollen. In the case of the Dutch *muricata* much more than 50 per cent. of the pollen has been sterile. Yet these are types which by virtue of their long history of close pollination might be expected to be among the purest of the species. On the other hand the race *grandiflora* B (Davis, '11, p. 203), and the western species *franciscana* and *venusta,* all open pollinated

species show hardly more than a trace of pollen abortion, and *Jamesii* from Texas only a small amount of sterile pollen. I have this winter tested the seed fertility of some of these species by germinating the seeds in Petri dishes after the method recently described (Davis, '15*b*). The Dutch *biennis* gave a germination of about 96 per cent., the Dutch *muricata* about 72 per cent., *grandiflora* B about 95 per cent., *franciscana* about 61 per cent., *venusta* about 87 per cent., and *Jamesii* about 91 per cent.

It is interesting to note in the above list that the Dutch *biennis* with its very high percentage of fertile seeds (96 per cent.) has extensive pollen abortion and the Dutch *muricata* with seed germination of about 72 per cent. has an even lower degree of pollen sterility. On the other hand there are species of *Œnothera* with both high seed and pollen fertility as illustrated by some races of *grandiflora, venusta* and *Jamesii.* I was especially interested in the conditions shown by my race *grandiflora* B with its almost perfect fertility both as to pollen and seeds. This race isolated from a collection of mixed seeds gathered by Tracy in 1907 at Dixie Landing, Alabama, has always seemed to me to present a type of unusual purity. The line was started in 1908 by a cross of two similar plants (Davis, '11, p. 203) representing the broader-leaved forms of *grandiflora* that were present at Dixie Landing and I have grown in small cultures several generations of the plant without noting departures from the type. I cannot accept the criticism of De Vries ('14, p. 348) that my race *grandiflora* B is impure because from the same collection of mixed seeds of Tracy's he obtained a diversified culture as I also reported (Davis, '11, p. 203) when the line was first isolated, and because De Vries and Bartlett found the Dixie Landing station "desolate" five years after the visit of Tracy. This type may prove to be nearer to the desired pure species than the Dutch *biennis*.

Jeffrey in recent papers ('14*a*, '14*b*, '15) has taken the position "that in good species the spores or pollen is invariably perfect morphologically" and from this standpoint refuses to consider *Lamarckiana* and other œnotheras as suitable material on which to base experimental studies on mutations. To him the mere presence of

abortive pollen suffices to stamp a form as hybrid in character. This represents an extreme view which in consideration of our ignorance of possible physiological reasons for pollen sterility can at present scarcely be claimed as more than an hypothesis. For the œnotheras we are greatly in need of cytological and physiological studies on pollen sterility more detailed than the incidental observations that have so far been published.

With respect to the abortion of ovules among the œnotheras our information is practically confined to the observations of Geerts ('09), mentioned above. It appears that in *O. Lamarckiana* and a number of other species only about 50 per cent. of the ovules develop embryo sacs. Other species also show varying degrees of ovule abortion. The ovules that fail to mature are represented in the capsules by a fine light brown powder known to all who work with œnotheras. Such powder is very common in the capsules of various species and their hybrids, and it seems probable that ovule sterility is as widespread in this group of plants as is the degeneration of the pollen. As in the case of pollen sterility we do not know to what extent physiological conditions may also be responsible for the abortion of ovules.

Pollen and ovule sterility involve of course the elimination from the life history of immense numbers of gametes and raise the following questions. Can it be that this elimination throws out of the life cycle types of gametes with germinal constitutions different from the gametes that matured and that function? It is possible that some of the *Œnotheras* species, in hybrid condition, regularly mature for the most part particular classes of gametes which in conjugation will perpetuate the genetic line of the parent plant? Gametes even when normally developed may still not function as when pollen grains fail to germinate upon the stigma because its secretions are not suitable. It must also be borne in mind that there are yet other phases of the life history when gametes may become ineffective as through failure to conjugate or because of a high mortality among zygotes, embryos, or young plants; such forms of infertility are expressed in sterile seeds or in weak offspring which never mature. Possibly the so-called "mutants" arise when unusual gametes from hybrids, occasionally surviving the ex-

tensive process of degeneration, form zygotes also able to survive and to develop plants diverging from the parents.

The subject of seed sterility among the œnotheras has scarcely been touched by the students of the group and yet it seems likely to become a factor of prime importance in its bearings on the problems of *Œnothera* genetics. Any worker among these plants shortly becomes aware of the fact that very many of the seed-like structures which he sows fail to germinate even though seed pans are kept for many weeks. De Vries makes frequent reference to the facts of seed sterility and the writer has in recent years recorded the number of seeds sown in cultures and the number of seedlings that develop. The results are most surprising and must have significance although what that may be remains for the future to disclose. A line of research has opened before us that will demand a special technique, for it is not enough to know merely that certain proportions of the seeds germinate within the time practicable for keeping seed pans under observation.

Seed-like structures sown on the earth are obviously lost for further enquiry as to the facts of their viability; a proportion of seedlings appear but as for the residue, that cannot be examined. The residue may contain viable seeds the germination of which is delayed, or it may consist wholly of sterile structures. We must develop methods that will ensure the rapid and complete germination of seeds in convenient receptacles such that the residue of sterile structures may be left for study after the seedlings have been removed and set in the earth. By such methods cultures of *Œnothera* may be grown in which one may feel confident that all of the viable seeds have germinated since by an examination of the residue it may be determined whether or not the seed-like structures have embryos. It is probably safe to say that no culture of *Œnothera* has as yet been described in which we may feel certain that the progeny of the sowing is complete. During the past winter I have tested the percentage of seed fertility in some fifty species and hybrids of *Œnothera* germinating the seeds on pads of wet filter paper in Petri dishes. With this method may advantageously be combined the clever practical suggestion of De Vries ('15, p. 190) of forcing water into wet seeds by air pressure thereby greatly

hastening their germination. A description of a method of seed germination which will, I think, prove to be satisfactory in genetical work on *Œnothera* may be found in the Proceedings of the National Academy of Sciences, Vol. I., p. 360, 1915.

The first investigator to make use of the facts of seed sterility in suggesting Mendelian interpretations of the behavior of *Lamarckiana* and certain *Œnothera* crosses has been Renner ('14) and his line of investigation has opened a field of research and speculation that must be reckoned with in the future. Renner has studied the seed structure in *Lamarckiana, biennis* and *muricata,* and in certain crosses among these forms. His conclusion on the genotype of *Lamarckiana* will illustrate the principles underlying the method of attack. Since *Lamarckiana* when crossed with *biennis* and certain other species gives in the F_1 hybrid generation the twin hybrids *læta* and *velutina* it may be assumed to develop two classes of gametes which function. These may be spoken of as the *læta* and *velutina* gametes and are produced in about equal numbers. When *Lamarckiana* is self-pollinated the *læta* and *velutina* gametes may combine in proportions to give 1 pure *læta*: 2 *læta-velutina*: 1 pure *velutina*. It is a fact that more than one half of the seeds of *Lamarckiana* fail to develop normal embryos and Renner concludes that these sterile seeds represent zygotes homozygous respectively for the *læta* and *velutina* factors. The fertile seeds develop from the heterozygotes with both *læta* and *velutina* factors combined and this combination gives the characters of *Lamarckiana*. *Œnothera Lamarckiana* may thus be an impure or heterozygous species breeding true because of the death of such zygotes as carry the factors for *læta* and *velutina* in homozygous conditions. This simple Mendelian explanation of the behavior of *Lamarckiana* points a line of interpretation and study certain to be fruitful in *Œnothera* research.

Among hybrids of *Œnothera* the seed sterility sometimes runs extraordinarily high. The most remarkable illustrations of this fact so far known appear in the second generations of crosses involving the Dutch *biennis* and the Dutch *muricata* which exhibit certain remarkable morphological peculiarities discovered and described by De Vries ('13). First generation hybrids of reciprocal crosses

between these species grown by the writer in 1913 gave data on seed germination in the earth as presented in Table I.

TABLE I.

F_1 Hybrids of Reciprocal Crosses between *O. biennis* and *O. muricata.*

Culture.	Cross.	Seeds Sown.	Sown in	Seedlings.	Germination.	Duration of Experiment.
13.33	F^1 *biennis* × *muricata*	673	Earth	139	20%	6 weeks
13.34	F^1 *muricata* × *biennis*	153	Earth	97	63%	7 weeks

It is probable from my experience with other species crosses that the viability of the seeds of these F_1 hybrids is really high and that the relatively low percentages recorded above are due to de-

TABLE II.

F_2 Hybrids of Reciprocal Crosses between *O. biennis* and *O. muricata,* Including Certain Double Reciprocals, Sesquireciprocals, and Iterative Hybrids.

Culture.	Cross.	Seeds Sown.	Sown in	Seedlings.	Germination.	Duration of Experiment.
14.41 (13.33a)	F_2, *biennis* × *muricata*	466	Earth	8	1.7%	9 weeks.
14.42 (13.34c)	F_2, *muricata* × *biennis*	205	Earth	35	12%	9 weeks.
14.43 (13.33a × 13.34)	double reciprocal (*b* × *m*) × (*m* × *b*)	73	Earth	8	11%	9 weeks.
15.31 (14.33 × 14.16)	sesquireciprocal (*b* × *m*) × *b*	267	Earth	25	9%	9 weeks.
*15.31 (14.33 × 14.16)	sesquireciprocal (*b* × *m*) × *b*	282	Petri dish	132	46%	6 weeks.
15.32 (14.16 × 14.33)	iterative *b* × (*b* × *m*)	22	Earth	1	4%	9 weeks.
15.33 (14.33 × 14.20)	iterative (*b* × *m*) × *m*	212	Earth	2	0.9%	9 weeks.
*15.33 (14.33 × 14.20)	iterative (*b* × *m*) × *m*	292	Petri dish	42	14%	7 weeks.
15.34 (14.34 × 14.16)	iterative (*m* × *b*) × *b*	217	Earth	47	21%	9 weeks.
*15.34 (14.34 × 14.16)	iterative (*m* × *b*) × *b*	373	Petri dish	73	19%	4 weeks.
15.35 (14.34 × 14.20)	sesquireciprocal (*m* × *b*) × *m*	246	Earth	43	17%	9 weeks.
*15.35 (14.34 × 14.20)	sesquireciprocal (*m* × *b*) × *m*	498	Petri dish	198	39%	7 weeks.
15.36 (14.20 × 14.34)	iterative *m* × (*m* × *b*)	198	Earth	51	25%	9 weeks.

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TABLE II.

F_2 HYBRIDS OF RECIPROCAL CROSSES BETWEEN *O. biennis* AND *O. muricata,* INCLUDING CERTAIN DOUBLE RECIPROCALS, SESQUIRECIPROCALS, AND ITERATIVE HYBRIDS.

Culture.	Cross.	Seeds Sown.	Sown in	Seedlings.	Germination.	Duration of Experiment.
14.41 (13.33a)	F_2, *biennis* × *muricata*	466	Earth	8	1.7%	9 weeks.
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layed germinations. But the figures for germination in the earth of F_2 hybrids and of double reciprocals, sesquireciprocals, and iter-

ative hybrids are most surprising in the degree of sterility or delayed germination shown. They are given in Table II., where are also presented the records of four cultures sown in Petri dishes in which the germination was complete as proved by an examination of the residue.

A comparison in Table II. of the record for culture 15.31 with *15.31, 15.33 with *15.33, and 15.35 with *15.35 will illustrate the gain in germination that may come through sowing seeds in Petri dishes. The percentages of germination presented above for the hybrids of *biennis* and *muricata* must not be regarded as expressing exactly the degree of seed fertility under the conditions of the experiments since with the harvests of seed are frequently found very many structures too large to be abortive ovules and too small to be counted as "seeds" in the sense of falling within the limits of seed size. These structures are probably undeveloped seeds but only a microscopical examination can determine this point; if so, their presence of course always lowers the percentage of zygotes capable of giving progeny.

Bearing in mind the fact that pollen sterility in *biennis* and *muricata* is 50 per cent. or more and that pollen abortion in the F_1 hybrids is very much higher (in fact very little good pollen is produced) the total amount of sterility both gametic and zygotic is simply amazing. Under such conditions how can the behavior of these hybrids be looked upon as indicative of anything but a most unusual situation, in itself very interesting, but far beyond the expectations of normal hybrid behavior. This remarkable degree of sterility among the hybrids of *biennis* and *muricata* is perhaps extreme for the œnotheras, but it serves to illustrate conditions extensively present in the writer's experience and doubtless also in the experience of others.

De Vries has described the hybrids between *biennis* and *muricata* as breeding approximately true which in the main has also been my observation. Apparently largely upon this behavior and that of certain other crosses he has reached the conclusion that hybrids between species of *Œnothera* are stable. In this opinion of De Vries I cannot agree for my crosses between *grandiflora* and certain small-flowered American species (Davis, '12 and '13), and between

biennis and *franciscana* have in the F_2 generations given abundant evidence of that extensive variation interpreted as segregation. I believe that the apparent stability of the very small progenies produced by hybrids of *biennis* and *muricata* simply means that the remarkably high mortality among gametes and zygotes of these hybrids, or the delayed germination of their seeds, has prevented the appearance in our cultures of the diverse types which theoretically would be expected. Any general conclusions on genetic behavior in the œnotheras which fails to take into account the phenomena of sterility rests upon insecure foundations.

It is true that we do not know to what extent physiological factors may affect seed sterility as well as pollen and ovule abortion. Nevertheless a main fact is clear, namely that seed sterility eliminates in certain *Œnothera* species and hybrids immense numbers of zygotes which fail to develop seeds. And, furthermore, we know for œnotheras that large classes of weak offspring are sometimes produced that are unable to reach maturity. Seedlings with white or yellow cotyledons, which quickly die, are not uncommon in my experience with *Œnothera* cultures; in certain cases they have appeared in very large numbers (Davis, '11, p. 222) and probably have important genetical significance. This situation in *Œnothera* finds a close parallel in the behavior recorded for a number of animals and plants. Thus Baur's "golden" variety of *Antirrhinum* is an impure or heterozygous form which besides reproducing itself throws a class of normal green plants and a class represented by weak yellow seedlings that shortly die. The yellow mice studied by Castle and Little although interbred always remain impure giving progeny heterozygous for yellow because of the death of zygotes with a double dose of the factor for yellow. A dwarf wheat isolated by Vilmorin cannot be fixed since it always remains heterozygous throwing talls but never producing homozygous dwarfs. The white female form of the clover butterfly, *Colias,* was found by Gerould always to give yellow offspring either because of the failure of the gametes carrying white to conjugate or because zygotes homozygous for white fail to develop. A form of *Drosophila* characterized by confluent wings has been found by Metz only in the heterozygous condition, always throwing normals and never breed-

ing true; flies homozygous for confluent wings are apparently not viable. Is it not possible that parallel or related phenomena are extensively present among the œnotheras? The mortality as shown by sterile seeds may indicate the elimination of large groups of forms divergent from the parent types, and some of the curious dwarfs and aberrant plants which again and again have been reported in *Œnothera* lines may be from zygotes barely able to survive the death-producing conditions that eliminate so many of their companions.

So far we have considered evidence chiefly of a negative character for the contention that many of the species of *Œnothera* are impure or hybrid species. We have tried to show that pollen, ovule, and seed sterility must all be reckoned with as conditions which may eliminate Mendelian classes of gametes and hold a line to a history of relatively true breeding even though the stream of germ plasm remain heterozygous or impure in character. The natural corollary of such behavior, if proven, might be the interpretation of so-called "mutants" as segregates from a hybrid stock that were able to survive the destruction meted out by conditions that produce sterility. To what extent the causes of sterility may lie in the history of gametogenesis or may be due to unfortunate combinations of gametes, or to what extent sterility is the result of physiological factors, these are problems that lie before us.

Let us now examine some positive evidence that certain species of *Œnothera* do form distinct classes of gametes and in consequence seem likely to be heterozygous in their constitution. That which first demands attention is the situation discovered by De Vries in certain first generation hybrids and by him named "twin hybrids." We have already referred to this phenomenon first described by De Vries ('07) for the behavior of *Lamarckiana* which as a pollen parent in crosses with other species of *Œnothera* gives not uniform F_1 generations but the two types *læta* and *velutina* (twin hybrids), produced in about equal numbers. Certain "mutants" of *Lamarckiana* also give twin hybrids under the same conditions as those produced by *Lamarckiana*. The behavior is so exact that the simplest hypothesis must suppose that *Lamarckiana* and these "mutants" form two classes of gametes which are fertile in these par-

ticular crosses. De Vries ('09) has also described "triple hybrids" when the "mutants" *scintillans* and *lata* are pollinated by such species as produce the twin hybrids from *Lamarckiana*. In such cases two of the forms have the characters of *læta* and *velutina* combined with those of the other parent, and the third form resembles the mother, either *scintillans* or *lata*. The phenomena of twin and triple hybrids is treated in detail by De Vries ('13) in "Gruppenweise Artbildung."

From a Mendelian standpoint the production of twin and triple hybrids is strong evidence that *Lamarckiana* and such of its "mutants" as behave in this manner are impure or hybrid since the male or female gametes are not uniform, a point which has been emphasized by several critics of the mutation theory. De Vries assumes that *Lamarckiana* forms its different classes of gametes as a result of its mutating instability but the precision of the process falls completley in line with what we know of Mendelian behavior. The remarkable studies of Shull show that crosses between *Lamarckiana* and *cruciata* give in the first generation polymorphic progenies of much greater complexity than the twin hybrids of De Vries. Shull's results have not been published in full but, as I understand them, they indicate the interaction of several classes of gametes, a condition very far from what would be expected if genetically pure species had been crossed.

Very interesting are the observations of Atkinson ('14) on first generation crosses between *Œnothera nutans* and *O. pycnocarpa*. These two forms are American species recently segregated by Atkinson and Bartlett from the *biennis* alliance. They have bred true in garden cultures. When *pycnocarpa* is pollinated by *nutans* twin hybrids appear in the first generation. In the reciprocal cross *nutans* ×*pycnocarpa* the same twin forms are produced and in addition a third type, making this generation a compound of three distinct forms, triple hybrids. Atkinson, apparently confident of the genetic purity of *nutans* and *pycnocarpa* assumes that the determination of the twin and triple hybrids takes place through a differential division in the zygote by which factors representing certain characters are side tracked in the suspensor cell and only those responsible for the twins and triplets pass on to the embryo. There is no

cytological evidence that the first mitosis in the zygote of a higher plant is ever a differential division. To the writer the situation indicates that one or both of the two species is heterozygous and that for this reason classes of gametes are formed, appropriate combinations of which give the twins and triplets. No data has been published respecting the sterility of these two species, either of pollen or ovules, and nothing of seed abortion. An understanding of the genetic constitution of the species is likely to be a difficult matter, but it does not seem probable that both are pure.

What shall be said of the probable purity of the plants of *Œnothera* and *Raimannia* with which MacDougal worked in his experiments designed to create new species by the injection of certain fluids into the ovaries. The parent material was reported to breed true, but the cultures were small and not long continued and there is no reason to suppose that a complete germination of the seeds was obtained. No information is given on the fertility of the species either with respect to the abortion of gametes or the proportion of good seeds. The material was not tested by cross breeding with other forms (the purest known) to determine whether the F_1 hybrids were uniform, a most necessary test in the establishment of a stock as homozygous. Thus from our present viewpoint we cannot accept MacDougal's conclusion since the probabilities are very great that the new types which appeared in his cultures were produced not as the result of the injections but because of the genetic impurity of the plants themselves.

In the above discussion the writer has taken definitely a Mendelian attitude in sympathy with the criticisms of Bateson and the studies of Heribert-Nilsson ('12) and of Renner ('14). There are constant suggestions of order in the phenomena of inheritance among the œnotheras which while they may not fall into simple schemes of Mendelian notation nevertheless do indicate system even though masked by complexities. That the complications at least in great part are due to the genetic impurity of the *Œnothera* material which has been so far the subject of study is the writer's belief. The difficulties that surround the analysis of *Œnothera* inheritance are probably in very large measure due to the extraordinary amount of sterility, gametic or zygotic, or both, that is present in the group.

Upon students of this genus rests the responsibility of obtaining data on this sterility and, if possible, of discovering its causes. The assumption that a line represents a pure species because it breeds true is not a safe foundation upon which to conduct experimentation in the œnotheras. This is the assumption upon which have been based many of the conclusions of the Mutationists, and from it we must dissent. We cannot depart from the principles underlying Mendelian methods of research which have so brilliantly opened the present century of biological investigation.

Finally what are the tests that must be applied to an *Œnothera* species to determine whether or not it is pure.

First.—There is the breeding test and that must be applied with such experimental methods of seed germination (Davis, '15) as will insure a complete progeny from the sowing, a progeny wholly representative of all types of viable seeds. Even then the breeding test is negative rather than affirmative in its conclusions. Should the form throw off numerous variants it naturally becomes a subject of suspicion, but should it breed true or relatively true that does not in this group of plants prove it to be homozygous in its germinal constitution.

Second.—Information must be obtained on the character and degree of sterility present, both gametic and zygotic. Sterility, unless shown to be strictly physiological in its character, suggests genetic impurity.

Third.—Cross-breeding tests must be planned and followed in which the form under observation is mated with material of known genetic purity. If the hybrid plants of the first generation are essentially uniform and the result of a normal germination of the seeds the indications are strong that the form is truly pure provided that the gametes are likewise normally fertile. If the hybrids of the first generation fall sharply into classes the material must develop gametes of different germinal constitutions and is consequently heterozygous. One favorable cross with a pure species may not be sufficient to establish the purity of a form; a number of favorable tests with pure types will carry increasing conviction.

It is thus not an easy matter to determine the fact whether or not a species of *Œnothera* is pure, and yet this is fundamental to

experimental studies in the group. On the assumption of specific purity the Mutationists rest their conclusions. This condition with respect to the characters studied is also basic to Mendelian experimentation. It need scarcely be emphasized that no species of *Œnothera* has as yet passed the tests for genetic purity outlined above and that consequently we have at present no standard material with which forms may confidently be mated in the test of cross-breeding. It should become the concern of *Œnothera* geneticists to find and isolate pure material as the starting point of further studies in experimental morphology. Whether such pure forms will be found among the wild species or as products of the garden time will determine.

University of Pennsylvania,
May, 1915.

LITERATURE CITED.

Atkinson, G. F.

1914. Segregation of Unit Characters in the Zygote of *Œnothera* with Twin and Triplet Hybrids in the First Generation. *Science*, XXXIX., 834, 1914.

Bartlett, H. H.

1915a. Additional Evidence of Mutation in *Œnothera*. *Bot. Gaz.*, LIX., 81, 1915.

1915b. The Mutations of *Œnothera stenomeres*. *Amer. Jour. Bot.*, II., 100, 1915.

1915c. Mutation *en masse*. *Amer. Nat.*, XLIX., 129, 1915.

Davis, B. M.

1911. Some Hybrids of *Œnothera biennis* and *O. grandiflora* that Resemble *O. Lamarckiana*. *Amer. Nat.*, XLV., 193, 1911.

1912. Further Hybrids of *Œnothera biennis* and *O. grandiflora* that Resemble *O. Lamarckiana*. *Amer. Nat.*, XLVI., 377, 1912.

1913. The Behavior of Hybrids between *Œnothera biennis* and *O. grandiflora* in the Second and Third Generations. *Amer. Nat.*, XLVII., 447, 1913.

1914. Some Reciprocal Crosses of *Œnothera*. *Zeits. ind. Abstam. u. Vererb.*, XII., 169, 1914.

1915a. Professor De Vries on the Probable Origin of *Œnothera Lamarckiana*. *Amer. Nat.*, XLIX., 59, 1915.

1915b. A Method of Obtaining Complete Germination of Seeds in *Œnothera* and of Recording the Residue of Sterile Seed-like Structures. *Proc. Nat. Acad. Sci.*, I., 360, 1915.

De Vries, Hugo.

1907. On Twin Hybrids. *Bot. Gaz.*, XLIV., 401, 1907.

1909. On Triple Hybrids. *Bot. Gaz.*, XLVII., 1, 1909.

1913. Gruppenweise Artbildung. Berlin, 1913.
1914. The Probable Origin of *Œnothera Lamarckiana.* *Bot. Gaz.,* LVII., 345, 1914.
1915. The Coefficient of Mutation in *Œnothera biennis* L. *Bot. Gaz.,* LIX., 169, 1915.

Geerts, F. M.
1909. Beiträge zur Kenntniss der Cytologie und der partiellen Sterilität von *Œnothera Lamarckiana.* *Rec. Trav. Bot. Neerland.,* V., 93, 1909.

Heribert-Nilsson, N.
1912. Die Variabilität der *Œnothera Lamarckiana* und das Problem der Mutation. *Zeits. ind. Abstam. u. Vererb.,* VIII., 89, 1912.

Jeffrey, E. C.
1914a. The Mutation Myth. *Science,* XXXIX., 488, 1914.
1914b. Spore Conditions in Hybrids and the Mutation Hypothesis of De Vries. *Bot. Gaz.,* LVIII., 322, 1914.
1915. Some Fundamental Morphological Objections to the Mutation Theory of De Vries. *Amer. Nat.,* XLIX., 5, 1915.

Renner, O.
1914. Befruchtung und Embryobildung bei *Œnothera Lamarckiana* und einigen verwandten Arten. *Flora,* CVII., 115, 1914.

Stomps, T. J.
1914. Parallele Mutationen bei *Œnothera biennis* L. *Ber. deut. bot. Gesell.,* XXXII., 179, 1914.

CONCRETIONS IN STREAMS FORMED BY THE AGENCY OF BLUE GREEN ALGÆ AND RELATED PLANTS.

By H. JUSTIN RODDY, M.S., Ph.D.

(*Read May 7, 1915*)

In 1898, I discovered that concretionary formations occurred in Little Conestoga Creek, Lancaster County, Pa. At that time, however, I was engaged in other studies and gave the concretions only a passing notice. But in the late summer of 1914, my attention was directed to the subject again by the reading of Dr. Walcott's paper on "Pre-Cambrian Algonkian Algal Formations" which appeared July 22, 1914. This paper made me realize the importance of a careful investigation of these particular stream formations as to characteristics, distribution, origin, etc. I began at once a careful and extended search in the Little Conestoga as well as in other streams for concretionary structures of recent formation. My search was amply rewarded by finding them in great quantities, and distributed throughout nearly the entire length of the Little Conestoga. I found also that they not only occur in the creek itself, but that quite large deposits of the concretions underlie the flood plain meadows along the creek banks. One of these in Kendig's Woods, two miles southwest of Millersville, Pa., is made up wholly of concretionary materials on the top of which forest trees of large size and considerable age are growing. This deposit covers nearly an acre to the depth of about 8 feet in the middle thinning out lenslike toward its edges. Another deposit along the same stream near Fruitville in Evan's Meadow, more extensive in area but of slighter depth, forms a substratum under a thick soil cover and has an average depth of about two feet. Deposited concretions occur under similar conditions in many other of the meadows along the stream as is shown by weathered concretions occurring in the soil and wash wherever wet-weather stream gullies have been torn through the soil cover.

Though these structures, as I shall show later on, are without doubt due to Algoid agency in the stream waters, it may be well to premise the full discussion of their origin by somewhat complete descriptions of their characteristics as to form, size, structure, etc. In this way the attention of botanists and geologists will be directed to their study and distribution, so that their significance as agents of rock formation and the flora, responsible for their growth, may be fully worked out.

Size and Shape.—The concretions both in the stream and in the deposits vary in size from peas to masses nearly a foot in diameter (see Fig. 1). The latter size is not very common in the

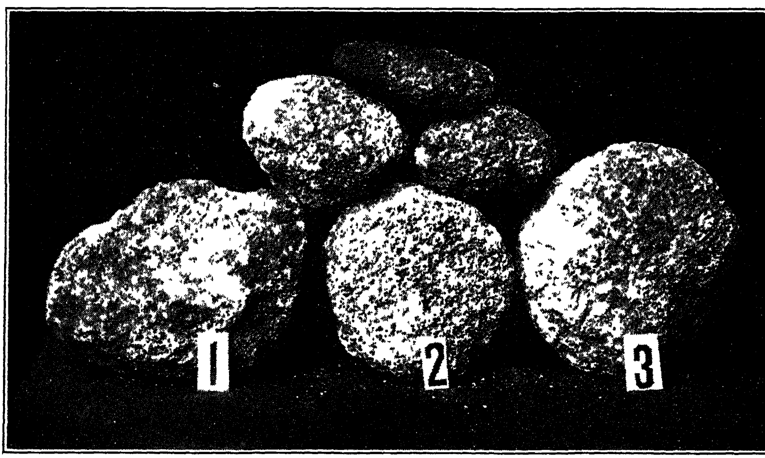

FIG. 1. A group of the concretions showing their size, shape, surface appearance and color. No. 1 is 7½x10 inches; No. 2 is about 5 inches in face diameter and 3 inches thick; No. 3 is 8x7x5 inches. The two smaller concretions above are typical, both in color and surface appearance, of growing specimens.

stream but many large concretions occur in the deposits probably because the smaller ones after deposition in land forms have been carried away in solution by percolating waters leaving only the larger forms. In the flood deposits in Kendig's Woods thousands of the concretions when I found the deposit last summer measured nearly a foot in length and six inches or more in transverse diameter.

The smaller concretions are invariably ellipsoidal in shape (see Fig. 1), and quite symmetrical unless broken by flood action. The larger sized concretions, though of the same general shape, are less symmetrical. Those in the stream are nearly always more regularly ellipsoidal than those of the deposits in flood plains and stream bars. This is, no doubt, due to their weathering through solution or to their having been broken by flood waters during their transportation to their present positions.

The concretions in the stream are quite firm in texture; those in the deposits are less compact. Both are porous and roughly coralline in general appearance and internal structure.

In color they vary from bluish green to whitish. The growing specimens in the stream are generally bluish green. All specimens after exposure for some time to sun, air, and rain or to the action of soil waters become grayish white.

Composition and Hardness.—Though the composition varies slightly from place to place yet all are limy deposits concentric around a nucleus. The main constituents in the concentric layers are calcium carbonate, silica and organic matter of vegetable origin. Upon dissolving out the limy constituents with dilute hydrochloric acid, a mat is often left of vegetable materials composed of the matted stems or tissues and cells of low type plants such as mosses and algæ.

Few of the specimens tested had a hardness as great as that of common calcite, most of them being about two in the scale of hardness. The weathered concretions are generally less coherent than those now forming in the stream.

The following table shows the main constituents of the concretions:

Constituents.	A.	B.
Organic matter	10% to 15%	1 to 12%
H_2O	1%	1%
SiO_2	12%	12%
$CaCO_3$	60% to 75%	70 to 80%
Fe	1%	2%
Al	Trace	Trace
$MgCO_3$	Trace to 1%	Trace to 1%

A of growing specimens.
B of specimens from flood plain deposit.

Structure.—Most specimens have as the nucleus a quartz or limestone pebble of the country rock. Near Millersville, where the stream flows for a mile or two parallel to an igneous dyke, the nuclei are diabase pebbles. But some specimens lack the stony nucleus having instead the limy layers concentric around a dark spot which proves upon close examination to be carbonaceous matter resembling nearly structureless peat. Probably this was originally a piece of wood or other vegetable tissue that carbonized after the concretionary laminæ had accumulated around it. This supposition has been verified in a number of cases by finding concretions with organic matter as nuclei (see Fig. 2).

FIG. 2. Sections of a group of the concretions showing the laminae, concentric arrangement of the laminæ, the nucleus or nuclear point, and eccentric manner of growth. One-third natural size. The nucleus in the small upper specimen is a small water worn quartz pebble. The larger upper specimen shows where the nucleus was broken out when the section was made.

The concretions with stony nuclei may always be detected by their higher specific gravity.

Around the nucleus of a specimen is layer on layer of the limy matter each lamina from one eighth to one fourth of an inch in

thickness. The laminæ are not equally compact throughout their thickness, but are open and porous within and quite solid without. A polished section of any concretion exhibits many concentric ellipsoidal layers with the nucleus nearly always eccentric and the successive layers with a greater thickness on the one side and two ends than on the other side. The thickness of the successive laminæ in any one direction out from the nucleus is nearly uniform. In other words, along any radius the inner layers are just as thick as the outer ones. When found in place in the stream where the concretions have not been disturbed for a long time, the down side laminæ are invariably a little thicker than those on the upper side. This indicates that the greater growth is downward.

In appearance and structure, the concretions of the Little Conestoga are very similar to the "Lake Balls" from Lake Canandaigua, New York, so vividly described by Dr. Clarke, under the name of "Water Biscuits." They are also somewhat similar though much larger in size to the oölitic sands found forming in great numbers in the waters of Great Salt Lake by A. Rothpletz and traced by him to the agency of blue green algæ.

Where Found.—Upon recognizing the importance of a thorough study of the Algoid concretions, I began a systematic search in all parts of the Little Conestoga as well as in other streams of both Lancaster and York Counties, Pennsylvania. My search showed that these objects abound in all parts of the Little Conestoga nearly from source to mouth. But no other streams in this part of the state have so far yielded any specimens. Those found in the sand bar in Lake Canandaigua near the mouth of Sucker Brook are probably also of stream origin, and I feel confident that a careful search in the brook would reveal at least some, if not many, of the concretions. Substances somewhat similar in composition occur in other lakes than Canandaigua though they do not have the concretionary form. Thus laminated reef-like accumulations of Algoid origin occur in Round Lake, New York, while marly or tufaceous deposits have accumulated for ages and are still forming in many lakes in Michigan, Wisconsin and Indiana. The tufa and thinolite described by Russell as forming in Pyramid Lake, Nevada,

are now regarded as of similar origin though differing much from the Little Conestoga concretions in both form and structure.

That concretions similar to those found in the Little Conestoga occur in other streams is evident from observations made in Center County, Pennsylvania, by Dr. Wieland, who, however, had not recognized them as of Algoid origin until I called his attention to the well known activity of some algæ in precipitating calcium carbonate. In a recent personal letter to me Dr. Wieland describes concretions that he found in 1888 in a stream near Lemont, Center County, Pa. He, however, says, "I just thought of them as very interesting objects from the viewpoint that they showed once more how abundant is CO_2 whether derived from plants or other sources. In short I knew too much and too little to make the least use of what I found."

Origin.—In 1854, W. Ketchell in the First Annual Report of the Geological Survey of New Jersey refers to *Chara* as active agents in the formation of fresh water marl. In 1864 Frederick Cohn found that a number of aquatic plants, especially *Chara* Mosses and Algæ, caused the deposition of travertine at the waterfalls of Tivoli. The deposition he attributed to the activity of the plants in absorbing carbon dioxide and so setting the lime carbonate free. That is, these low type plants consume carbon dioxide and exhale oxygen. When this is done in water containing calcium bicarbonate they deprive that salt of its second molecule of carbonic acid and the insoluble neutral carbonate of lime is precipitated.

W. S. Blatchley and G. H. Ashley in their report on the lakes of Indiana in 1900 also refer to the activity of plants in the precipitation of insoluble lime carbonate. But they also thought that the dissolved lime brought into the lakes by streams and deposited mechanically by evaporation was a more important agency than the plants.

In 1900 C. A. Davis discussed the origin of the marls of the lakes of Michigan and came essentially to the same conclusion as Cohn. He says:

"But in water containing amounts of salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be consid-

ered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates of the oxygen set free by the plants. Of these calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the folllowing chemical equation, $CaH_2(CO_3)_2 + O \rightarrow H_2O + CaCO_3 + CO_2 + O$, in which the calcium bicarbonate is converted into the normal carbonate by the oxygen liberated by the plants and both carbon dioxide and oxygen set free, the free oxygen possibly acting still further to precipitate more calcium monocarbonate, $CaCO_3$."

Dr. F. W. Clarke in "Data of Geochemistry" says:

"That Dr. Davis' theoretical equation (given above) rests on no experimental basis."

In an article in *Science* dated December 14, 1914, J. Claude Jones, of the University of Nevada, says that the tufas of Salton Sea and of Pyramid Lake owe their origin to blue green algæ. He shows that wherever these plants are present in Pyramid Lake the gravels are cemented together and wherever the algæ are absent no trace of the tufas can be found.

Dr. Clarke ascribes the origin of the "Water Biscuits" of Lake Canandaigua to the same agency.

Miss Josephine Tilden in *Minnesota Algæ* (1910) says that *Gleocapsa calcarea* forms a calcareous crust (with other lime secreting forms) on boards where spring water from a trough drips down constantly.

Weed in his classic report (1889, U. S. G. S.) on the rock formations of the hot springs of the Yellowstone National Park shows that travertine as well as siliceous sinter are deposited through the aid of algæ.

Dr. B. M. Davis, of the University of Pennsylvania in a very interesting paper (*Science,* Vol. VI., July 30, 1897) describes the algæ and bacteria active in the formation of the travertine and siliceous sinter deposits in Yellowstone Park.

Dr. MacFarlane, of the University of Pennsylvania, in speaking of the activities of thermophilic algæ of hot spring and geyser regions, ascribes many rock formations throughout the earth's history as due to the work of fresh water algæ especially of the group Cyanophyceæ.

Evidences That the Active Agents of the Concretionary Formations in the Little Conestoga are Blue Green Algæ.

That the concretions described in the first part of this paper are the result of life processes of plants may be proved in a number of different ways. (1) The color of all growing specimens in the stream is the characteristic bluish green color of the Cyanophyceæ, while those exposed to rain and sunshine are grayish white. Careful microscopic examination also of such growing specimens reveals a varied thallophytic flora mainly of the Cyanophyceæ. Species of the genera *Gleocapsa, Gleotheca, Aphanocapsa, Nostoc, Oscillatoria* and *Rivularia* have been identified. Associated with these are several of the green algæ (Chlorophyceæ). Many species of the Diatomaceæ and Desmidaceæ which generally live in close association with blue green algæ have also been identified and have, no doubt, contributed the siliceous matter which is disseminated through the calcareous matrix. Among the diatoms, species of the genus *Navicula* both in free forms as well as stalked forms on algæ are quite prominent. The *Charas* are also occasionally present, contributing a small percentage of so-called marly material. Some bacteria have also been found in association with the other plants but the bacteria have probably had little to do with the calcareous deposition, but may contribute the iron which I find present in every concretion that I have analyzed.

(2) The arrangement and structure of the laminæ also favors the view that these concretionary accumulation are due to life processes. That periodic accretion alternates with a period of quiescence is shown plainly by the concentric laminations of nearly uniform thickness. The open porous nature of each lamina within and the more solid character without, like the concentric arrangement, is due without doubt to the seasonal conditions of the region. Since algæ are essentially thermophilic plants, each winter destroys many of them and stops the growth of most of the rest and thus at the beginning of the plant year (spring) few and widely scattered algæ at first produce slow and scattered accretion of the limy matter; later the plants become more abundant and by summer they are crowded over the surface of each mass. This distribution of the algæ seasonally would naturally have its effects upon the struc-

ture and arrangement of the limy matter giving a decided though rough coralline appearance to the inside portion and a more compact texture to the outer part. The theory just given has been confirmed by a study of the distribution of the algæ on the concretionary bodies through the seasons. The fact also that when the limy matter is dissolved out with acids, a mat of vegetable chains and cells remains nearly as large as the original concretion is also confirmatory. Even in the concretions which are centuries old as those in the forest covered deposit in Kendig's Woods the dead cells and chains of blue green algæ may be found.

(3) Lime secreting algæ are found in the Little Conestoga during the entire year but abound from May till December. They occur not only in the water but encrust many objects, in a few places forming small reef-like accumulations similar to those in Round Lake, New York.

(4) Quite an array of investigators, among whom we may mention Agassiz, Bigelow, Gardiner, Murray, Finckle, Vaughan, Walther, Drew, Matson, Dall, and Sanford, have studied at first hand the activities of algæ of the genera *Lithothamnion* and *Halimeda* and also some of the bacteria in various parts of the ocean and in many seas. All have come to the conclusion that many of the so-called coral reefs owe their existence partly and often largely to the activities of these lowly plants. The Bermudas, the Bahamas, the Laccadive and Maldive Archipelagoes, Funafuti, and extensive rock beds in the Floridian Peninsula have all originated through plant agency as much as through coral polyps. If this be true, it is not only possible but probable that fresh water blue green algæ throughout all the ages have caused and are still causing the precipitation of rock materials from minerals in solution in streams and fresh water lakes.

(5) Weed has proved that the concretions formed in geyser basins and known as Geyserites are formed by algæ which through life processes cause the precipitation of the siliceous matter held in solution in the hot water.

(6) The observation that the laminar accretion seems to proceed more rapidly on the under side of a concretion proves that the formations are not due to mechanical precipitation of lime carbonate

through evaporation or change of temperature. It does, however, suggest that the secretion or precipitation is chemical and dependent on a life process that produces conditions for chemical reaction where the plants or animals are most abundant.

(7) Conway MacMillan in *Minnesota Plant Life* says:

> "Some slime moulds have the power of incrusting their tiny fruit bodies with lime which they extract from their soil or from rain water which falls upon them. Such forms are often observed in Minnesota upon dead wood or fallen leaves, generally, in moist shady places in the deep forest. Some of the blue green algæ have the power of encrusting themselves with lime and in watering troughs and tanks there sometimes occurs a calcareous formation reminding one of the deposit in old tea-kettles. Such a crust is true limestone extracted from the water by the chemical activities of the algæ."

Upon a larger scale the blue green algæ have been conclusively shown by Weed to be important factors in travertine formation in the hot springs and geysers of Yellowstone National Park.

Dr. MacFarlane without knowing of my discovery in the Little Conestoga Creek has expressed the opinion that these apparently insignificant plants have throughout all the ages played and are still playing in all waters an important part in the formation of limestones and dolomites.

(8) The fact that many more or less ancient rocks have been demonstrated to be of algoid origin by various scientists and are similar to the Little Conestoga concretions in their concretionary or laminated structures or both is favorable to the view that algæ are just as important agencies in rock formations in the present geological epoch as in the past. The similarity of *Cryptozoön proliferum*, Ozarkian oölitic formations, *Newlandia frondosa, Camasia spongiosa, Collenia compacta, Collenia undosa* and other structural forms in rock formations to the work of recent algæ in hot spring and geyser regions has been vividly shown by Walcott, Wieland, B. M. Davis and others. Some, at least, of the above-named formations can be strikingly duplicated in their structural peculiarities by the Little Conestoga concretions and reef-like masses of Round Lake,—the Potsdam-Hoyt formation of New York state being especially like what would result were infiltrating waters, cementation, and other solidifying agents or processes to act for a long time upon the great mass of flood deposited concretions of the Little Conestoga in Kendig's Woods.

Mineral Content of the Little Conestoga Waters.

One would infer from the number of concretions growing in the Little Conestoga and also from the thickness of each lamina in a concretion that the mineral content of this stream's waters is high. I have verified this by determining the salinity of the stream under varying conditions. The salinity in a wet month was 330 parts in a million, while in a dry month this rose to 365 parts in a million. Streams in which I have found no trace of concretionary structures have a much lower salinity, the Big Conestoga Creek for example having a salinity of 190, the Pequea Creek 195, and the Susquehanna, in March, above the mouth of the Pequea and below the mouth of the Big Conestoga, about 200 parts in a million. The various springs flowing into the Little Conestoga have an average salinity nearly as high as that of the Little Conestoga itself.

The basin of the Little Conestoga is underlain with much more soluble limestone than any of the other streams so far investigated. This accounts for the high salinity of its waters and also for the distribution of the concretions so far as we know that distribution. Further search and study will certainly reveal that many streams of the world contain concretionary structures and determine the conditions of their distribution and formation. I trust the beginning I have made in the investigation of stream concretions will lead to a wide and thorough study of this interesting and important biological as well as geological problem.

The various facts tabulated on page 257 and correlated with the fact that the blue green algæ are about equally abundant in the various streams mentioned in the table would seem to indicate that deposition of $CaH_2(CO_3)_2$ is always going on in all the streams during the growing season, but that when the salinity is low solution by the stream waters balances deposition and no concretions are formed. When, however, the salinity is high, solution can not take place and laminated structures due to seasonal or other changes are formed either in concretionary form or more rarely as reefs. This is put forward as a working hypothesis, many more observations and analyses are needed however before the various problems connected with these formations can be fully solved.

Table Showing Relation Between the Salinity of Streams and the Presence of Calcium Carbonate Concretions.

Stream or Spring.	Month.	Salinity, Parts in One Million.	Nature of Salinity (Chiefly).	Concretions Present in Stream.
1. Little Conestoga.........	Feb. 5	330	$CaH_2(CO_3)_2$	Abundant
2. Little Conestoga.........	March	300	"	"
3. Little Conestoga.........	April	365	"	"
4. Branch Run, tributary to Little Conestoga.......	April	91	"	None
5. Big Conestoga...........	Feb.	152	"	None
6. Big Conestoga...........	March	100	"	None
7. Big Conestoga...........	April	150	"	None but many gasteropods
8. Duing's Run, tributary to Big Conestoga.........	April	195	"	None
9. Pequea Creek............	April	195	"	None
10. Donegal Run............	April	404	"	Abundant
11. Nissley's Dam in Donegal Run, further upstream than 10...............	April	400	"	Many but small
12. Donegal Run near source...	April	230	"	None
13. Bellaire Branch of Donegal Run.................	April	208	"	None except near mouth
14. Little Chickies...........	April	170	"	None
15. Big Chickies.............	April	171	"	None
16. Big Chickies farther upstream..............	April	174	"	None

Further Notes on Concretionary Formations in Streams.

Since writing the above I have been fortunate enough to find a new locality for concretions. Knowing that Donegal Township, Lancaster County, comprised a notably large area of Cambro-Ordovician limestones, I judged that its streams would be favorable to the growth of calcareous concretions through the agency of blue green algæ. Search on April 25, in Donegal Creek, revealed these objects in greater abundance than in the Little Conestoga. One meadow of fully 12 acres bordering the stream about one mile northeast of Marietta was found to be underlain with a bed of concretions not less than a foot in average thickness throughout its entire extent. And this was under a soil cover of more than a foot in depth that had, apparently, resulted from the weathering and disintegration of the same objects. The great flood deposits of concretions in this and neighboring meadows were paralleled by large quantities in the stream itself, fully one fifth of the stones in some

places in the stream channel being of concretionary origin as shown by their shape, laminated structure, and composition.

The finding of the new locality is of great interest. It shows that a careful, intelligent, and systematic search will reveal these formations in many other regions of the world wherever the proper conditions exist for calcareous and siliceous precipitation through the life processes of plants.

But the geological significance of the great meadow deposits also needs emphasis. The large accumulation in the Donegal Township Meadow represents a comparatively long period and this indicates a considerable antiquity of the plants which form the concretions. Then too, such a bed of closely packed concretions is highly suggestive of the manner in which some ancient rock beds originated. For were such accumulations of concretions as those in the Donegal Meadows to be consolidated by the action of infiltrating waters, pressure, heat and chemical change solid rock beds would result nodular in appearance and concretionary in structure hardly distinguishable from the Hoyt Potsdam beds of New York.

Species of the following genera of the Cyanophyceæ are found associated with the calcareous concretions occurring in Donegal Creek, Lancaster County, Pa..: *Glœocapsa, Microcystis, Cœlosphærium, Aphanocapsa, Oscillatoria, Rivularia, Nostoc, Chroococcus.* There are also species of *Protococcus,* many species of Diatoms, several species of Desmids, various species of the Chlorophyceæ, several species of Phæophyceæ, and species of Rhodophyceæ.

THE CONDITIONS OF BLACK SHALE DEPOSITION AS ILLUSTRATED BY THE KUPFERSCHIEFER AND LIAS OF GERMANY.

By CHARLES SCHUCHERT.

(Read May 7, 1915.)

Stratigraphers do not agree as to the conditions under which the black bituminous shales so often met with in American Paleozoic marine deposits were laid down. Among the more striking of such formations may be mentioned the Quebec, Martinsburg, Collingwood, Utica, Maquoketa, Genesee-Portage, Ohio, Chattanooga, and Caney, formations ranging from the Ordovician to the Pennsylvanian. To aid in the interpretation of such black shales, the writer presents herewith the main results set forth by Professor J. F. Pompeckj, of the University of Tübingen, in a publication that will not be of wide distribution in America.[1] The following is a decided condensation and in part a free translation of his exhaustive paper, which is replete with bibliographic references.

The Kupferschiefer of Germany are of Middle Permian age, and occur near the base of the Zechstein, the time of marine invasion over the previous continental series known as the Rotliegende. In general, the bituminous dark shales occur above the basal Zechstein conglomerate and below the Zechstein dolomite, and occupy an area of at least 60,000 square kilometers in middle and western North Germany. The average thickness of the copper shales over wide areas is about 30 inches, but varies from nothing to a maximum and exceptional local thickness of 35 feet. However, in many places there are no black shales and then the equivalent deposits, or the basal strata of the invading Zechstein, may be conglomerates, sands, shaly limestones, or dolomites. In other words, the black bituminous shales do not prevail everywhere, and the same is true of the metal sulphides.

[1] "Das Meer des Kupferschiefers," Branca-Festschrift, 1914, pp. 444–494.

The copper-bearing shales usually succeed the basal conglomerates or sands and finally become gradually more and more calcareous, passing upward into the normal Zechstein dolomite of wider distribution. The latter has an abundant though monotonous fauna indicative of peculiar marine conditions and not much like that of the Tethyian mediterranean to the south, which is of normal sea environment. The paleogeography indicates an inland sea, bounded by continuous land, in the north by Fennoskandia across to England, thence south to France and Belgium, and east over South Germany to Bohemia. In the east only were there limited connections with the Russian and Arctic Zechstein sea. The previous orogenic movements resulting in the Paleozoic Alps of central Europe had been greatly reduced, so that the streams flowing into this Permian sea were sluggish and delivered only the finest of muds and solution materials, while those flowing out of regions of igneous rocks were charged in addition with copper, zinc, and silver.

The Kupferschiefer are fissile, tough, dark to black, highly bituminous (6 to 20 per cent.), clay shales with considerable calcareous material that increases in amount upward (locally to 45 per cent.). Copper sulphides variable in quantity and nature are present, and because of this ore the strata have been mined in Germany for seven hundred years. Under the microscope the shale is seen to be made up of finest clay substance colored yellow-brown to black by bitumen. Throughout the clay there are scattered, layered, or aggregated in the form of thinnest lenses varying amounts of tiny crystals of calcite and needle-like splinters of quartz. Black coaly dust is also more or less abundant and especially among the clay particles.

The flora and fauna of the Kupferschiefer are small and at best do not include more than 1 land stegocephalian, 2 land reptiles, 17 fishes (5 selachians, 1 crossopterygian, the rest ganoids) with structures indicating forms that lived on or near the bottom of the waters, 1 nautilid, 1 gastropod, 1 scaphopod, 10 bivalves, 3 bryozoa (Fenestellidæ), 5 brachiopods, 1 problematic starfish, and 11 species of land plants. This assemblage is brought together from many localities and the species of fishes are usually based on single specimens, indicating that the biota is not a natural assemblage, but is

made up of land and marine forms plus fishes, most of which appear to be of fresh water habitat. The only common fossils are the ganoid *Palæoniscus freieslebeni, Lingula credneri, "Asterias" bituminosa* (problematic), and the small bivalves *Nucula beyrichi* and *Bakewellia antiqua* (sometimes in colonies). In other words, the life consists of land-derived forms (3 vertebrates and 11 plants), fishes (5 probably marine and certainly bottom-feeding, and 12 apparently of river origin), and 22 marine invertebrates all but one of which are forms living on the bottom of the sea, attached to it or to floating objects. While the invertebrates indicate plainly that the copper shales were laid down in the sea, the great scarcity of fossils shows that the forms recovered are in the main not in their normal habitat. It appears that only 3 species (the invertebrates cited) were able to adapt themselves to the peculiar conditions of the copper-depositing seas. Not a single scavenging animal is found, and the fact that so many fishes (17 species) were present as food (*Palæoniscus freieslebeni* is often more or less decomposed by sulphur bacteria) indicates that the bottom had no scavengers and that it was not a favorable place for any kind of life.

Pompeckj has carefully studied the fishes, and as all or most of them are carnivorous (some are shell-feeders) the question is raised: On what could they have fed, since there was so little bottom life? He admits that there may have been present an abundance of soft-bodied and shell-less invertebrates on which they preyed, but finally concludes that it is much more correct to assume that most of the fishes (at least 12 species) were drifted into the sea from the rivers. If they also lived in the sea, it must have been in the oxygenated surface waters or the shallow shore regions. On the other hand, the invertebrates present indicate that nearly all of them fed on microscopic plants and animals (no ostracods are present, however) and it is perfectly natural to assume that the surface and sun-lit waters abounded in a varied plankton, as do the seas and oceans of today. It was this world of minute forms, the plankton, that rained into the depths, feeding the sparse brachiopod and molluscan life and the common sulphur bacteria.

Moreover, it is the abundant surface plankton that in all probability has furnished most of the bituminous matter, assisted further

by the land-derived fishes, while the coaly substance has resulted from the land plants. Along the shores, in the oxygenated waters, there probably also was an abundance of sea-weeds and among them doubtless lived most of the invertebrates preserved in the Kupferschiefer. The marine plants are broken up by the storms, and the water currents plus the undertow generated by the waves and tides drag this material into deeper waters, where it is slowly rotted and further altered by the sulphur bacteria. There results a foul bottom, free of oxygen, and reeking with carbonic acid and sulphuretted hydrogen gas. The chemical reactions set up here (diagenesis) result in the deposition of the metal sulphides (copper, zinc, silver) and the bituminous alteration products.

The paleogeography, as stated above, indicates an inland and almost land-locked sea. Into such a basin the currents generated in the oceanic areas can at best enter but little, and that such did not enter in any marked degree is seen in the almost complete absence of floating and swimming invertebrates. As for the general physical conditions, Walther thinks of stagnant waters, with marine swamps; Kayser of quiet bays of inland seas with foul bottoms; and Dosz of stagnant places like the present bays around the island of Oesel, where the bottoms are rich in iron sulphide deposits, the healing or medicinal muds. Pompeckj, however, finds more or less valid objections to all of these suggestions, and thinks the best present analogue to be the Black Sea, whose physical and organic conditions are now well understood through the work of Andrussow and Lebedintzew. In other words, the Kupferschiefer sea is "a fossil Black Sea" in nearly all its characteristics except depth.

With regard to the conditions of the Black Sea, it is an inland, relic sea, which was once a part of the Tethyian mediterranean. Its greatest length is about 715 miles and its maximum width 380 miles (making its area 170,000 square miles), and it attains 7,360 feet in depth. Flowing into it are many rivers, among the largest of which are the Danube, the Dnieper, and the Don. Its only outlet of surface water is through the strait and over the barrier of the Bosporus into the Sea of Marmora and thence through the strait of Dardanelles into the Ægean Sea and the Mediterranean. A compensating but smaller inflow of salt water (salinity 3 per cent.)

occurs at greater depths. The shores are high and bold on the northeast, east, and southwest, and flat on the north and northwest.

Andrussow[2] has described the physical and bionomic conditions of the Black Sea as follows: Beyond the shallow marginal waters of 600 feet depth there is no bottom-living life (benthos), while in the surficial fresher waters down to about 750 feet there is a more or less great abundance of floating, usually microscopic, open-sea forms (plankton) and the larger, free-swimming life (nekton), collectively also spoken of as the pelagic biota. This upper layer of freshened water and its peculiar life conditions are brought about by the enclosed nature of the deep basin, the inflowing of immense quantities of less dense fresh water that remains at the surface or is there evaporated, and a deep-seated, partially compensating current of salt water from the Sea of Marmora through the strait of Bosporus. It is estimated that it takes about 1,700 years to renew the entire salt-water content of the Black Sea.

Because of these differences between the lighter surface and the heavier bottom salt waters, there is no vertical streaming nor convection currents beyond 750 feet of depth, and therefore no replenishing of the deeper marine waters with the oxygen that is so necessary for the maintenance of benthonic life. At the depth of 600 feet, hydrogen sulphide begins to form (33 c.c. in 100 liters of water) and increases rapidly with the depth to 3,000 feet (570 c.c.) and then more slowly to the bottom of the sea. The formation of the H_2S is in the main due to the sulphur bacteria. Hand in hand with the increase of the H_2S goes the decrease of the sulphates in the sea water and the precipitation of the carbonates and iron sulphides.

That the aëration of marine waters, and also the generation of sulphuretted hydrogen may be better understood, a digression into the studies of oceanographers becomes necessary. The atmospheric gases, oxygen and nitrogen, are absorbed at the sea surface more abundantly in cold than in warm latitudes, and the quantity absorbed is again variable under varying pressures and chemical conditions of the water. This complex subject, too long to state here, may be

[2] "La Mer Noire," Guides des Excursions, VII[e] Cong. Géol. Internat., St. Pétersbourg, 1897, Art. XXIX.

studied in Krümmel's "Handbuch der Ozeanographie," I., 1907, pages 292–317. Furthermore, the amount of oxygen is increased when there is an abundance of assimilating plants, as in the areas of the sea-weeds and diatoms. The gases are then distributed by the general water circulation to most parts of the oceans and even into the greatest depths. In general, there is an abundance of oxygen down to 350 feet, but in the tropics it is wanting in the greater depths of the shelf seas. The oxygen is consumed by the animals and by various hydro-chemical processes and consequently diminishes in quantity as it is carried down from the surface and over the bottom, but the quantity of nitrogen remains constant. Sir John Murray states further that in the streaming open ocean of today there is usually an abundance of oxygen even at the greatest depth, due to the sinking heavier and colder polar waters, but this is not the case in partially enclosed seas which are more or less cut off by barriers and where the water is said to be "stale," and in the deeper layers of which vertical circulation is restricted.

Similar stagnant conditions "prevail in several Norwegian 'threshold fjords,' or on a smaller scale in the oyster-'polls.' In such places the bottom is thickly covered with organic matter; a slimy black mud is formed, swarming with bacteria that produce sulphuretted hydrogen, which spreads through the water, combining with the oxygen to form various sulphates. This causes the oxygen to decrease and finally to disappear altogether, when the sulphuretted hydrogen begins to appear free in solution. It gradually spreads upwards, until the water is devoid of oxygen and contains free sulphuretted hydrogen, at a depth of only 100 fathoms in the Black Sea, and in the oyster-basins in autumn often at merely a couple of meters below the surface. In summer the 'bottom-water' of the oyster-'polls' lies stagnant, but in the course of the autumn and winter it is generally renewed by the supply of comparatively heavy water from without; then the sulphuretted hydrogen disappears and the oxygen returns, producing thus an annual change in the gaseous conditions of the deeper parts of the oyster-'polls.' In autumn the state of things may become critical for the oysters, which are suspended in baskets at a depth of 1½–2 meters; it hap-

pens occasionally that the animals all die at this time by suffocation through want of oxygen or by sulphur poisoning."[3]

Johnstone[4] states that "In some parts of the sea, as for instance in the 'dead grounds' of the [very shallow] Bay of Kiel, in some parts of the Black Sea, and perhaps in parts of some of the Norwegian fjords, where the water circulation is defective, and where there may be a deficiency of oxygen, very remarkable bacteria are to be found. These are the sulphur bacteria, the occurrence of which is not, however, confined to these habitats. In the places I have mentioned sulphuretted hydrogen is evolved from the decomposition of dead organic matter, and this sulphuretted hydrogen, to us a vilely smelling and poisonous gas, is utilized as food substance by the bacteria. Such a microbe as Beggiatoa takes in the SH_2 and oxidizes it so that the sulphur is deposited in the cells of the bacterial colony, and the hydrogen appears as water. This is the form of assimilation of the organisms. Then some of the sulphur thus resulting from the decomposition of the SH_2 is oxidized to sulphuric acid. This is the form of respiration of the organism. It requires some source of nitrogen for the formation of its living proteid and this it obtains from the minute quantities of nitrates and nitrites which exist in solution in the water in which it lives. But it requires very little nitrogen compound, for whereas a higher animal may require to oxidize some of the living nitrogenous tissue of its own body in order to obtain its energy, the sulphur bacterium oxidizes the sulphur stored in its cells as the result of the assimilation of the SH_2. Thus the proteid part of the cell is protected from waste, and the minimal quantity of nitrogenous food-stuff suffices."

Krümmel states that the troughs of the Baltic Sea renew their deeper water irregularly and periodically. In the Rügen and Bornholm troughs (about 325 feet deep) the renewal takes place at least once and more rarely twice each year, in the Danzig trough (about 325 feet deep) nearly every year, and in the deeps off Gotland and in the Gulf of Bothnia usually only after many years. All these troughs get the new deeper water from the western Belt Sea and more rarely also from the Öresund east of Denmark.

[3] Sir John Murray, "The Depths of the Ocean," 1912, pp. 257–258.

[4] "Conditions of Life in the Sea," 1909, p. 264.

To return to the Black Sea and its sediments, these are of three categories: (1) from the shore to about 120 feet occur the accumulations of sandy detritals; (2) from 120 to 600 feet is found a gray-blue sticky ooze, often replete with small fragile shells, mainly of Modiola; and (3) in the greater depths the bottom is covered with (*a*) a tough, sticky, black ooze, with much precipitation of iron sulphide, an abundance of diatoms and fragments of the youngest stages of bivalves, all of which organisms are from the plankton, and (*b*) the dark blue ooze poor in iron sulphide and richer in the finest-grained $CaCO_3$, which in places forms thin banks, and an abundance of pelagic diatoms. Zones 1 and 2 alone have benthonic organisms, with the greatest abundance between 210 and 600 feet; the latter is the zone of *Modiola phaseolina* and a great variety of bivalves and gastropods (68 species occur in the shallower waters).

The Kupferschiefer sea, like the Black Sea, had bottom waters with about the average normal salt content, as proved by the typical Zechstein invertebrates. However, because of the lack of oxygen and the high content of sulphuretted hydrogen and CO_2 an abundant bottom life was impossible. That the top water of the Kupferschiefer sea was also fresh is proved by the wide distribution of the freshwater fishes in the sediments, the widely uniform spreading of the thin zone of shale, and the presence of land plants and land vertebrates. If all the water had been salty, the fine muds should have been laid down in a narrow zone bordering the margin of the sea, and this is not the case in the Kupferschiefer sea. The slow decomposition of the organic remains (mainly the plankton) and the lack of oxygen in the depths led further to the formation of the bituminous content (from 6 to 20 per cent.).

As the Black Sea goes down to 7,360 feet, the question must be asked: What was the depth of the Kupferschiefer sea? A positive and exact answer can not be given, but the small thickness of the shale over wide areas, combined with its intimate and variously modified connection below with the Zechstein conglomerate and above with the Zechstein dolomite, and its shallow-water life, show that "it is a deposit of the shallowest and shallower seas." To the reviewer, the depth seems to be well within that assigned the

continental shelf seas, *i. e.,* less than 600 feet. The freshwater covering Pompeckj thinks was thin.

Just as in the Black Sea the marginal fresh waters are depositing sands and other littoral sediments that are free of bitumen, so in the Kupferschiefer sea there is some evidence of marginal sands, sandy and clayey limestones, and regions free of metal sulphides.

Later, the black sea of Permian time gradually changed, first locally and finally everywhere, into the limestone-dolomite or Zechstein sea, still, however, an inland sea but devoid of muds and bituminous materials. In the shallow regions nearer the shores arose reefs of bryozoa, but at best the Zechstein sea, even when in widest connection with the ocean, had a small and monotonous fauna.

In an earlier paper Pompeckj[5] discusses a similar deposit, the zone of *Posidonomya bronni* of the Upper Lias of Germany. It seems desirable to cite also some of the details given in this paper, because they are somewhat different from those concerning the Permian. The deposits are fissile, calcareous, bituminous, dark shales rich in iron pyrite. Locally there are also horizons of sandstone, barren of life, and layers of stinking limestone. These deposits are found in northwestern Germany (about 40 feet thick) and France.

In Germany (Swabia and Franconia) the fossils consist of diatoms and coccoliths, horn sponges, very rarely a sea-urchin, crinids (sometimes with stalks over 50 feet long), a few forms of brachiopods, about 18 species of bivalves (of which the only common one is *Posidonomya bronni,* but this very thin-shelled form is at times exceedingly abundant; also *Pseudomonotis substriata, Inoceramus dubius, Pecten contrarius*), and rarely a gastropod or crustacean (Eryon). Besides the common bivalves mentioned, there are many ammonids, belemnids, sepias, fishes (selachians, many ganoids, teleosts), ichthyosaurs, plesiosaurs, and crocodiles. With the marine forms are associated drifted land plants (cycads, and often a great abundance of conifer logs, now carbonized), beetles, and dragons of the air (pterosaurs).

[5] "Die Jura-Ablagerungen zwischen Regensburg u. Regenstauf," Geognos. Jahresheften 1901, XIV. Jahrg., pp. 178–186.

It is apparent from the above that the common fossils are here again those of the nekton (saurians, fishes with most of the ganoids probably of freshwater habitat, belemnids, sepias) and drifted land plants. Of the benthos, only a few species of bivalves are common, and, while the ammonids are also bottom-dwellers and occur commonly as fossils, their empty shells were probably drifted into this black sea. The crinids were also drifted in, for the only specimens found attached are on conifer wood, hanging head downward; otherwise roots of these pentacrinids do not occur.

In general it may be said that the Liassic deposits and the habitat of the fossils of the time of *Posidonomya bronni* agree best with those of the present Black Sea. Since this is true, it follows that the physical conditions of the *bronni* sea must have been very much like those of the Black Sea, *i. e.,* it was a Liassic Black Sea into which drained rivers, causing the surface waters to be more or less freshened, and bringing land plants, logs, and ganoid fishes. However, there are also marked differences, chief among which is the far less amount of decomposition of the soft parts of ichthyosaurians and sepias, of which fleshy parts are often preserved, a condition that never occurs in the Kupferschiefer. Finally, the abundance of the Liassic bivalves points to the shallow waters of the Modiola ooze of the Black Sea, and therefore to depths of less than 600 feet.

It seems to the reviewer that the present Black Sea, with its great depth and widespread foul conditions, is an exceptional example, and that in all of its features it may have no fossil analogue. The Kupferschiefer and *P. bronni* seas along with the American Ohio sea of Upper Devonian time and the Chattanooga sea of the Mississippian period appear to agree with the essential conditions of the Black Sea, except as to depth. All of the fossil Black Seas appear not to have been deeper than 600 feet.

Foul bottoms are clearly due to a lack of water circulation, either because there is no wide connection with the oceanic areas or because there are inadequate vertical or convection currents. The latter conditions may have been more abundantly attained in warm climates than in cool ones, due to the fact that the heavier colder waters sink to the bottoms and so oxygenate them. In this the present is the exceptional condition when compared with most of

geologic time. In such stagnant areas, be they small or large in area, or shallow or deep, the oxygen is soon consumed by the organisms of the benthos and the depths become stale and lifeless. As the sulphur bacteria are ever present, but thrive best in the stale bottoms, they soon take the ascendancy there and fill the waters with an ever greater quantity of sulphuretted hydrogen, provided they are furnished with the dead organisms on which to feed and thus to increase in number. On the other hand, the sun-lit, aërated surface waters are the realm of the green and assimilating micro-plants, the free algæ, which convert the inorganic carbon dioxide into their organic bodies, and these upon their death rain into the deeps to form the essential food of the bacteria of the foul bottoms.

That depth of water is not the first essential for the production of foul bottoms has been shown by the examples cited (almost from the surface down), but it does seem that large areas must have depths greater than 300 feet, for otherwise the high waves generated by the storms would set up a vertical circulation and so at least periodically replenish the oxygen and take away the foul gases of these depths. Therefore it would seem that Black Seas of large size should be deep (300 feet or more) and land-locked basins whose oceanic connections are more or less cut off by submerged barriers. Smaller areas are the elongated troughs and rounded holes below the general level of the sea floors, while the smallest and shallowest areas are the bays that are more or less separated from the seas by closely approaching headlands, banks, and bars, or the marine swamps that are filled with eel-grass, mangroves, and other modified land plants.

ON THE RATE OF EVAPORATION OF ETHER FROM OILS AND ITS APPLICATION IN OIL-ETHER COLONIC ANESTHESIA.

By CHAS. BASKERVILLE, Ph.D., F.C.S.

(Read April 23, 1915.)

It is conceded that the anesthetic agent must get into the blood for distribution and for eventual elimination, whatever theory of general or central anesthesia one may support. The anesthetic agent has normally been introduced into the blood by inhalation or intravenously. It is normally eliminated mainly via the lungs.

The intestinal mucous membrane of vertebrates is well known as an efficient transmitter of gases to and from the blood. Pirogoff[1] appears to have been the first to mention the administration of ether by this route. Liquid ether was used until Magendie gave warning as to the danger of its use and ether vapor was substituted. During the same year Roux,[2] y'Yhedo[3] and Duprey[4] employed liquid ether or aqueous mixtures to induce complete anesthesia. Although Pirogoff's enthusiasm prompted him to predict the supplanting of the inhalation procedure by the rectal method, references to it disappeared from the literature until 1884. Then Mollière[5] revived interest in the method by using a hand bellows for forcing the ether vapor into the intestine. Variations in the technique were introduced during the same year, but the experiences of Yversen, Harter, Bull,[6] Weir,[7] Wancher[8] and Post[9] showed more or less diarrhœa

[1] "Recherches pratique et physiologiques sur l'etherization," St. Petersburg, 1847.

[2] *J. d. l'academie d. Sciences*, 1847, 18.

[3] *Gazette med. d. Paris*, 1847.

[4] *Academie royale de medicine*, March 16, 1847.

[5] *Lyon Medical*, 45, 1884.

[6] *N. Y. Med. J.*, March 3, 1884.

[7] *Med. Rec.*, 1884.

[8] Cong. internat. d. Sciences med., 1884.

[9] *Boston Med. and Surg. J.*, 1884.

and melena as after-effects. These after-effects, which one case of death directly attributable to the procedure, caused the method to again fail in securing serious recognition until 1903 when Cunningham[10] employed air as a vehicle for sweeping the ether vapor into the colon. In 1909 Leuguen, Money and Verliac[11] used oxygen as the vehicle for the ether vapor. Buxton[12] in his splendid book on "Anesthesia" says that he found the procedure most satisfactory for certain operations, for example, those having to do with the mouth, nose, etc., but he remarks "Deaths have occurred." Sutton's[13] introduction of a return flow tube for these gases introduced and unabsorbed constituted a distinct advance in anesthesia by colonic absorption.

In an effort to avoid certain well-known difficulties in intravenous anesthesia, Gwathmey experimented with mixtures of normal saline solution and ether per rectum. The concentration of ether in the aqueous solution was so small that excessive volumes of liquid were needed, and furthermore the ether parted from the solution so very rapidly that experimentation along those lines was abandoned. Gwathmey then applied a solution of ether in olive oil. As oil and ether make perfect solutions in all mixtures, it was his hope to reduce the total bulk of the fluid introduced into the colon by using a stronger solution of ether in oil than is possible with any known aqueous mixture. As oils are lubricants, it was also hoped to avoid the irritation of the mucous membrane previously noted. The ether may always be separated from the oil by warming, but unless the temperature of the mixture is suddenly raised to an excessively high point, the ether passes off deliberately. It was thought that the evaporation of the ether would induce some cooling of the mixture with a consequent checking of the evaporation and its absorption. These premises coupled with slow absorption by the colon in comparison with the rapid elimination by the lungs would auto-

[10] Cunningham and Leahy, *Boston Med. and Surg. J.*, April 30, 1905; *Vide* also Dumont, *Correspond. Bl. f. Schweitzer Aerzte*, 1903; 1904; 1908; Krugeline, *Wiener klin. Woch.*, Dec., 1904.

[11] *Compt. rend. Soc. Biol.*, June, 1909.

[12] "Anesthesia," London, 1907.

[13] For full account of technique and literature, see "Anesthesia," by Gwathmey and Baskerville, Appleton, New York, pp. 431–457, 1914.

matically regulate any anesthesia that might be induced in this manner. As a result, Gwathmey presented a paper before the seventeenth International Medical Congress in London in 1913 on the work with animals done by himself and Wallace.

At the request of my co-laborer, Gwathmey, I undertook an investigation on the rate of evaporation of ether from oils to secure the following information that might be of service to him in his further application of his ideas with human subjects:

1. A comparison of the rate of evaporation of ether from different mixtures of ether and the same oil.

2. A comparison of the rate of evaporation of ether from the same per cent. mixtures of different oils and ether.

3. The influence of surface on the rate of evaporation was determined.

As the result of much preliminary experimentation, the following mode of procedure was settled upon. Large glass tubes were calibrated to 1 c.c. from 20 c.c. to 105 c.c. The mixtures of 25, 50 and 75 per cent. of oil and ether were carefully placed in the tubes. The tubes were weighted with lead and placed in a thermostat, whose temperature was so regulated as not to vary more than $\pm 0.03°$ C. from 37° C., the same being controlled by a toluene + mercury temperature regulator. All connections (gas, water, etc.) were made with lead pipe for safe use over night, as occasion arose. The water in the bath was stirred by a system of paddles and shaft operated through belt and pulleys by a small hot air engine. The tubes were immersed in the bath to within 2 cm. of the tops. During the first five minutes two readings were made in each case to get the highest point to which the volumes expanded upon heating up to 37° C. After that readings were made every five minutes for two or three hours.

Since the evaporation of any liquid depends upon the partial pressure of that liquid at its surface, the higher the glass wall above the surface of the oil-ether mixture, the heavier the column of ether vapor resting on the surface of the mixture, the slower will be the evaporation, consequently the different oil mixtures with the different percentages of ether were experimented with in the same tube filled to the same height in each experiment.

In the experiments to determine the influence extent of surface played upon the rate of evaporation, the same precautions were taken as to height of walls of the containing vessels. In the largest areas worked with, this involved using as much as 600 c.c. of the mixture. As the 75 per cent. mixture had been found most satisfactory clinically, this was determined with that mixture only.

The ether used was that prepared under my supervision and was 97 per cent. absolute with 3 per cent. absolute alcohol, being free from acids, aldehydes, and water.

The oils used were of three types, vegetable, animal and mineral, being respectively, olive, cotton seed, corn, peanut and soya-bean; cod-liver and lanolin (anhydrous); and Russian mineral oil. All the vegetable oils, except olive, were refined by a process devised by

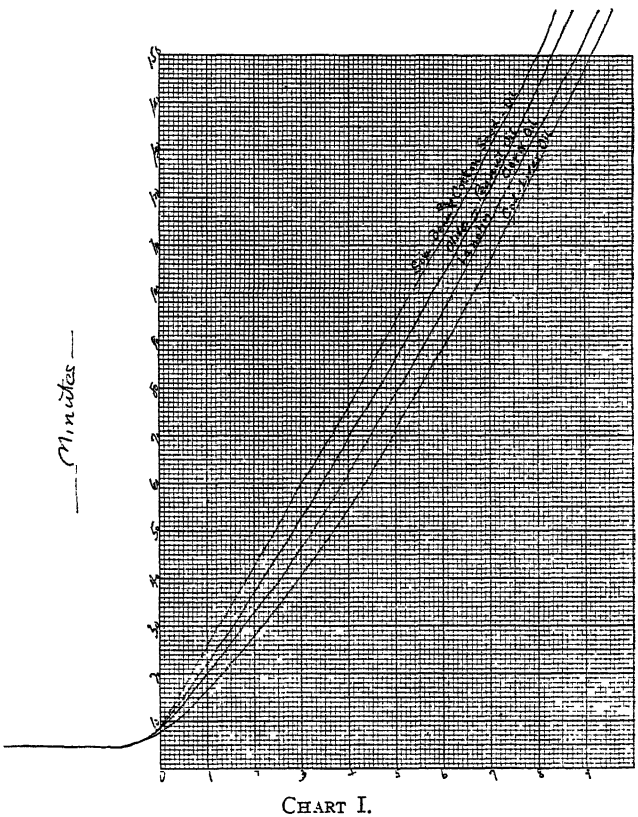

CHART I.

the author[14] and were neutral. The other oils were purchased in the open market.

The experimental work was carried out by Mr. Hyman Storch, under my direction.

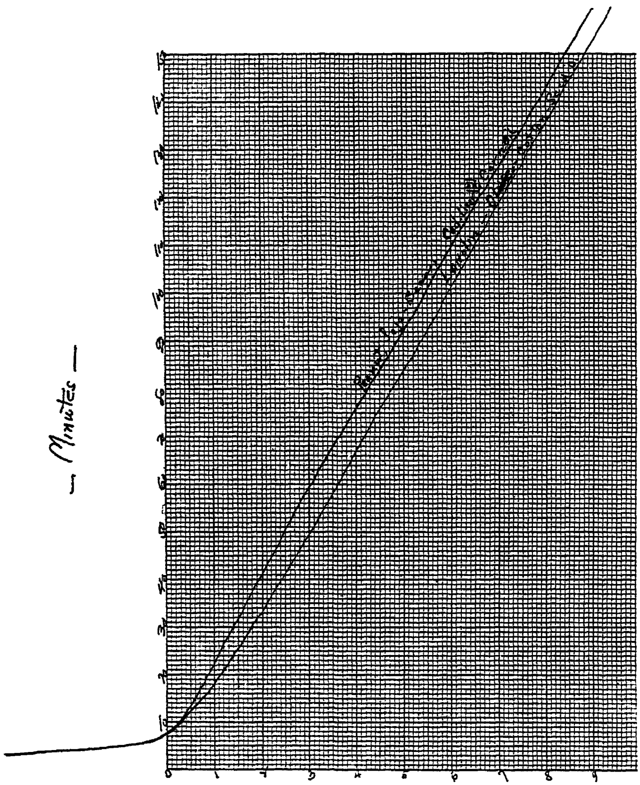

CHART II.

The data obtained for the 25, 50 and 75 per cent. mixtures vegetable and animal oils are shown graphically in Charts I., II. and III. In the curves the abscissæ show the percentage of ether evaporated (based on volume measurements) and the ordinates time of the evaporation.

Chart IV. (selected at random from charts made for each oil) shows the difference in rate of evaporation 25, 50 and 75 per cent. mixtures with one oil.

[14] "Refining Oils," *Oil, Paint and Drug Reporter*, May, 1915.

Chart V. shows the effect of increased surface on the rate of evaporation. One oil only was selected to show the principle, which is: the rate of evaporation bears a direct ratio to the surface exposed.

These experiments were made in glass, hence they do not disclose all the factors in the conduct of such mixtures in contact with the walls of the colon, for there the principles of osmosis and diffusion are involved. But these observations demonstrated several striking facts:

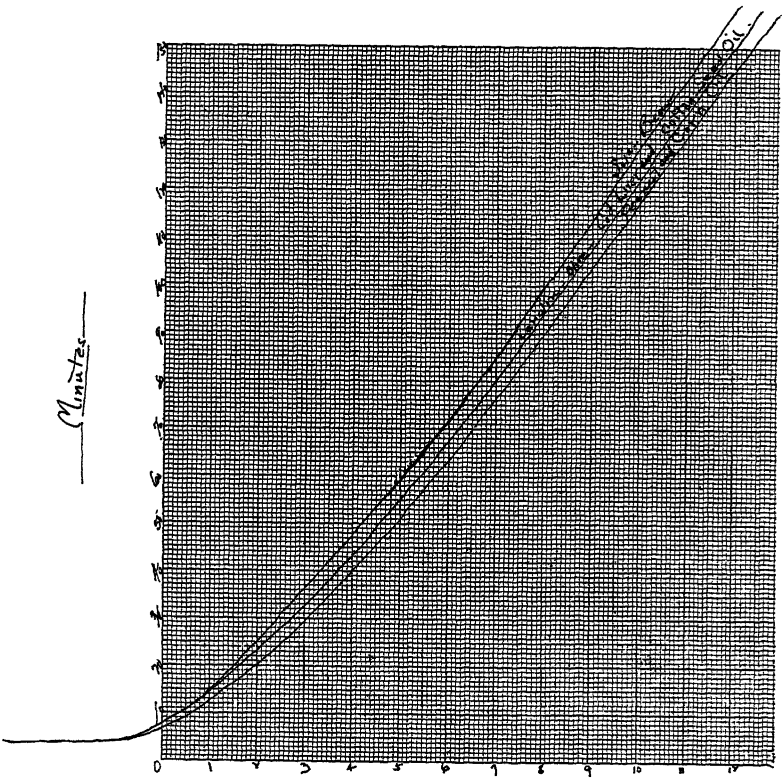

CHART III.

1. While ether boils at 34.6° C., it does not escape violently from an oil-ether mixture, as from an aqueous mixture when the mixture is heated higher, namely, to the body temperature of 37° C.

2. The *rate* of separation of ether from the oil quickly acquires a definite and fairly fixed speed.

The significance of this conduct cannot fail to be of great importance, for by this means the proper content of ether may be main-

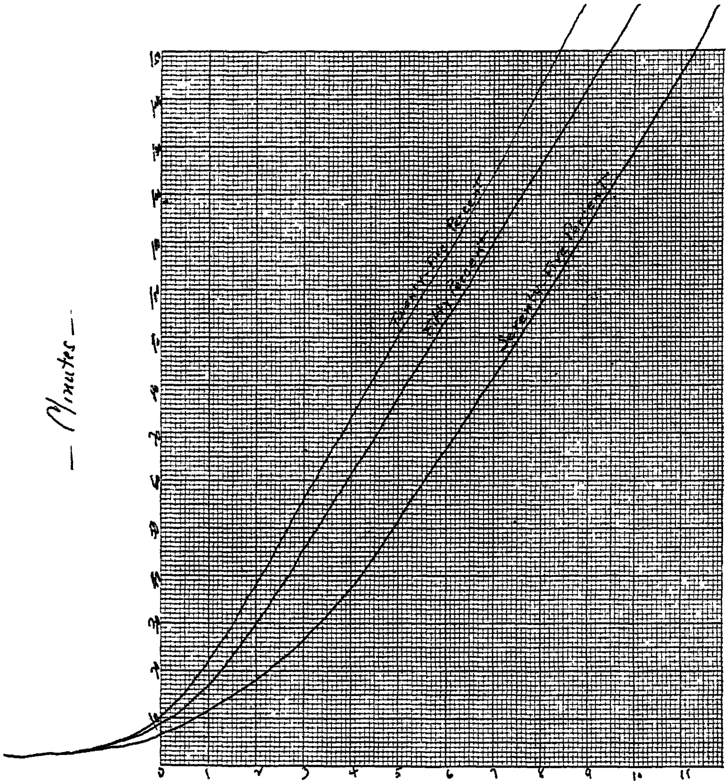

CHART IV.

tained in the blood to produce any desired physiological effect that has a quantitative relation thereto, for example, the third or surgical stage of anesthesia.[15]

The last mentioned has been demonstrated clinically by Wallace, who found respiration and blood pressure fully maintained, and Gwathmey and others with records to date of about 1,000 human cases. So far, not a case of post-ether pneumonia has been encoun-

[15] In this connection it may be stated that about 30 mils of a 75 per cent. mixture to 20 lbs. of body weight is administered as an enema.

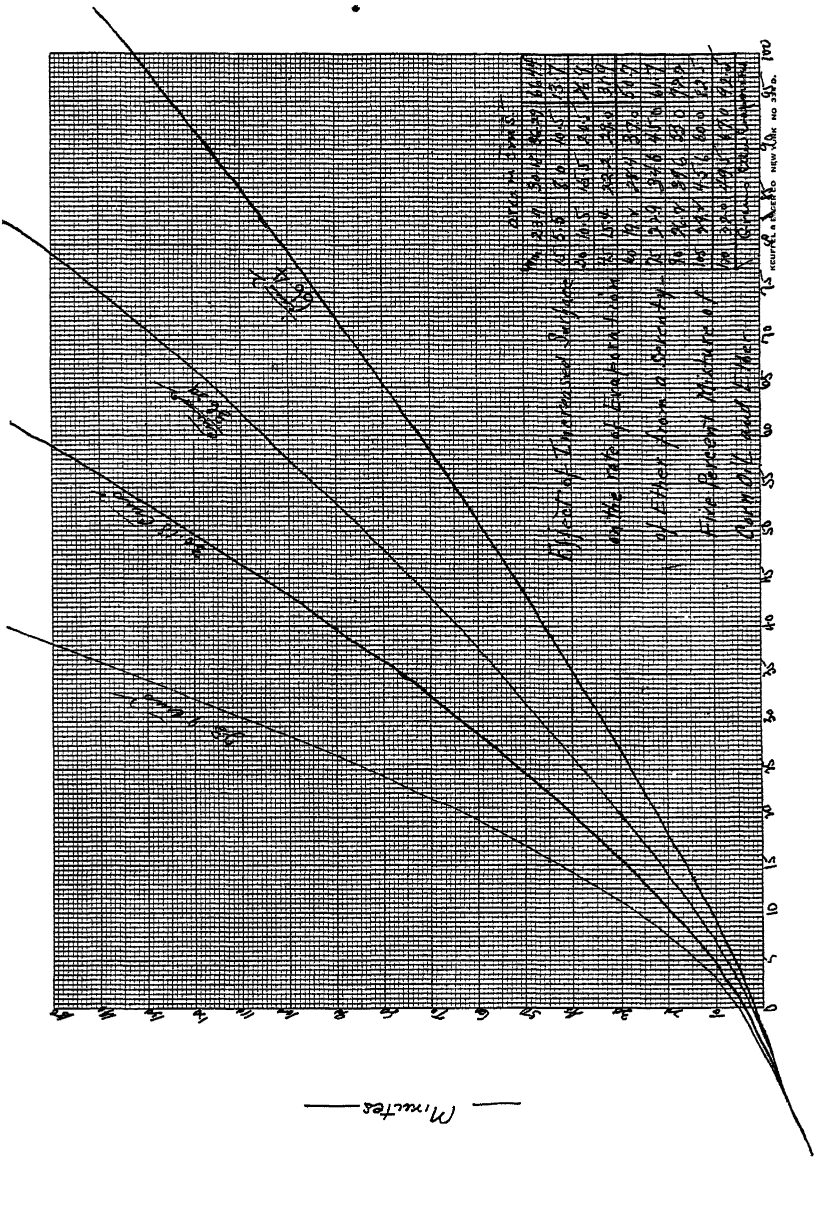
Effect of Increased Sulphur
on the rate of Evaporation
of Ether from a Solvent
Five Percent Mixture of
Corn Oil and Ether
Minutes

CHART V.

tered. The after-effects usually associated with inhalation anesthesia, unless induced by the most improved modern technique, are virtually absent, including post-anesthetic nausea. Its use for special cases involving the head, breathing passages, etc., is superior. Although having had the privilege of attending clinics, I am not qualified to pass judgment upon its value, but from what I have learned, if necessary, "Give it to me that way."

College of the City of New York.

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SYMPOSIUM ON THE EARTH: ITS FIGURE, DIMENSIONS AND THE CONSTITUTION OF ITS INTERIOR.

I.

THE INTERIOR OF THE EARTH FROM THE VIEWPOINT OF GEOLOGY.[1]

BY T. C. CHAMBERLIN.

(*Read April 24, 1915.*)

For some time past there has been a marked drift of geologic opinion from the older tenet of a molten earth toward the conviction that the earth is essentially solid. This has been quite as much due to the contributions of kindred sciences as to the growth of geologic evidence, but this has made its important and concurrent contributions.

The great granitic embossments that constitute the most distinctive feature of the oldest known terranes were formerly regarded as solidified portions of a primitive molten earth and seemed to serve as witnesses of the verity of the former liquid state. A few years ago, however, it was determined—almost simultaneously in several countries where critical studies on these formations were

[1] The discussion of this topic at the session of the Society was without manuscript or notes and this paper, prepared some weeks later, is less a reproduction of the original discussion than a substitute for it.

in progress—that these granitic masses are not only intrusive but that they were thrust into formations that had previously been formed at the surface of the earth. These surface formations have thus come to stand as the most ancient terranes now known. These earliest accessible depositions imply the preëxistence of a substantial foundation formed at a still earlier date. Neither of these gives any clear intimation that lower formations are different from themselves. So far then as the record runs back, it testifies to substantial solidity in the outer part of the globe at least. The record implies, indeed, that molten matter was then present within the earth, but it gives no certain measure of the ratio of the molten to the solid part. There is no determinate evidence that a molten condition was a preponderant state, even in the interior, at any stage covered by the lithographic record. The interior conditions of the earliest stages that antedate the lithographic record are to be reached only by indirect and remote rather than direct and immediate inference. Under the influence of inherited presumptions, it may seem to many still probable that the interior of the mature earth was once dominated by a molten condition at some remote stage, but the phenomena of powerful inthrusting, so often shown in the intrusions of the igneous element into the early terranes, seems to imply that at the Archean stages the molten element was in the strong grasp of such stresses as are natural to a rigid globe and was therefore then but a minor and passive factor, not a controlling one.

When it is considered that, if the earth were once wholly molten, the material for all the stratified rocks of later ages must have been derived from the primitive crust after it was formed and forced into positions of erosion—or from matter extruded through it—the absence, according to present knowledge, of any great area of rocks bearing the distinctive characteristics of the congealed surface greatly weakens the assumption that the postulated molten state ever obtained in the mature earth.

A study of the stress-conditions of the interior of the earth seems to call for a similar reversal of the inferences once drawn from the igneous rocks. From the earliest well-recorded ages, the exerior of the earth has given evidence of broad topographic reliefs

in the form of great embossments and basins. These surface configurations must have conditioned the localization of extrusions and the deployment of the effusive material. If the lavas arose from a general and abundant source of supply which was responsive to general and powerful stresses, vestiges of this vital relation should be found in the volume and deployment of the lava floods. If, on the other hand, the molten material was but a fraction of the environing mass, variously distributed through it, the result should be a multitude of driblets squeezed out here and there in such special situations as the controlling stresses required, or else forced into weak portions of the earth-body where the stresses were less imperative. Now there is abundant geological evidence that the earth-body has been subjected at repeated intervals to strong compressive stresses by which its outer portion has been folded into mountainous ranges, or pushed up into great plateaus, while masses of continental dimensions have been raised, relatively, to notable heights, and the bottoms of basins and deeps have sunk reciprocally to even greater relative depths. The internal stresses which these deformations imply should have made themselves felt proportionately on any great mass of liquid in the interior—if it were in existence—and extrusions proportionate to the great deformations of the rigid material should have accompanied such diastrophism. But, while liquid extrusions took place somewhat freely at the times of great diastrophism, it was not, at least in my judgment, at all commensurate with the deformative stresses implied by the diastrophic results in the solid material.

Nor was the concentration of the extrusions indicative of origin from a molten interior or from great residual reservoirs of liquid rock. If such ample sources of liquid had existed they might naturally have been expected to have given forth, under the great stresses then seeking easement, correspondingly great floods of lava. Yet no single lava flood seems to have attained more than an extremely small fraction of the mass of the earth or of the known solid matter of its region. Even when the sum total of the most massive series of successive floods in a given region are taken together—though the successive issues stretched over a considerable period—they rarely rise above a most insignificant fraction of earth-mass or even of the

regional segment of it with which they are associated. Instead of really massive flows, implying ample sources of supply and great forces of extrusion, the record shows rather a multitude of little ejections or injections of more or less sporadic distribution. The logical implication of these is the preëxistence of a multitude of small liquid spots, or liquifiable spots, scattered widely through the stressed earth-masses and yielding to stress as local conditions required.

This inference is supported by the great variations in altitude at which lavas are given forth. The most impressive illustrations of this are found in current volcanic action whose relations in altitude are precisely known. So far as ancient conditions can be restored, they appear to fall into the same general class as existing conditions. Current outpourings of lava range from the sea bottom to altitudes of many thousands of feet above sea level, a vertical range of several miles. Extrusions occur at these significantly diverse altitudes simultaneously or alternately or in almost any time-relations, and sometimes in the most marked independence of one another in spite of the natural sympathy of such events in a common stressed body. A multitude of facts of detail, some of which are singularly cogent, imply that the lava sources of present volcanoes are disconnected from one another in the interior, and hence independent in action, as a rule, though sometimes they show sympathy without showing liquid connection. The sources of lava seem to be meager in general, and the eruptive agencies seem to be controlled by narrowly local conditions. There is an absence of evidence that the lavas in the craters and necks of volcanoes are parts of great liquid masses below, responsive to the common stresses of a large region.

Thus geological evidence, when critically scrutinized, seems to be distinctly adverse to the existence of even large reservoirs of molten matter within the earth; it points rather to the presence of scattered spots, very small relatively, on the verge of liquefaction, which pass by stages into the liquid form and are then forced out by the differential stresses that abound in the earth body, each such local liquifying center commonly giving forth driblets of lava and gas, at intervals, none of which often rise to more than an extremely minute fraction of the earth mass or even of the subterranean mass contiguous to the volcano.

A revised view of the nature and location of earth-stresses seems also to be required by what is now known of earth-conditions. Under the former dominance of the tenet of a molten globe, it was natural to assign to the stress-differences of the earth a distinctly superficial localization and limitation; they were thought to be affections of "the crust" almost solely. Hydrostatic pressures were of course recognized as affecting the deep interior, but these were obviously balanced stresses, they were ineffective in deformation. The stresses supposed to give rise to the great reliefs of the earth's surface were thought to be very superficial. But the stresses imposed by known deformative agencies are not all superficial, nor are their intensities always greatest at the surface. According to Sir George Darwin, the stress-differences generated in the earth by the tidal forces of the moon are eight times as great at the center of the earth as at the surface. So also, according to the same authority, the stresses engendered by changes in the rotation of the earth are eight times as great at the center as at the surface and are graded between center and surface. The tidal stress-differences are relatively feeble but are perpetually renewed in pulsatory fashion. Those that arise from rotation belong to the highest order of competency. The stress-difference that would arise at the center of the earth from a stoppage of the earth's rotation, would, according to Darwin, reach 32 tons per square inch. Changes of the rate of rotation are almost inevitable when great diastrophic readjustments take place. Such periods are to be regarded as critical times at which great floods of lava should be poured forth from the interior if liquid material were there in great volume ready to respond to the changes of capacity which the deformation of the earth's sectors and the change in the spheroidal form would inevitably impose.

Not to detain you with other considerations, the foregoing seem best to comport with an essentially solid state of the earth's interior, if they do not point rather definitely to such a state. Even if they stood alone, they would seem to make a prevailing solid state the most tenable working hypothesis.

But they are far from standing alone; the geological evidences are strongly supported by considerations that spring from several kindred lines of inquiry. The testimony of astronomic evidence

has been given by Dr. Schlesinger. The import of seismic studies, the subject of Dr. Reid's contribution, lends very special support to the view that the interior of the earth is elastico-rigid at least to the extent that distortional waves have been shown to pass through its interior. It seems certain already that this condition prevails throughout much more than half the volume of the earth; concerning the rest, the deep interior, the seismic evidence is perhaps still to be regarded as indeterminate. But on the seismic evidence it does not fall to me to dwell.

The tidal studies of Hecker, Orloff and others lend support to the tenet of a rigid earth but they fall somewhat short of conclusiveness. The brilliant experimental determinations of Michelson and Gale, correlated with the computations of Moulton, have carried the evidence to the point of preliminary demonstration. They need only to be adequately repeated and verified to become final, so far at least as elastic rigidity can be indicated by the response of the earth-body to solar and lunar attractions. The special feature of most critical value in the demonstrations of Michelson and his colleagues is the high degree of elasticity shown by the almost instantaneous response of the earth to the distorting pull of the tide-producing bodies. This cuts at the very base of concepts founded on the supposed properties of a viscous earth. These tidal determinations of elasticity are in close accord with the seismic evidences of elasticity. The two are happily complementary to one another. The one deals with the earth as a whole under rhythmical series of increasing and diminishing stress-differences springing from external attraction; the other deals in an intensive partitive way with earth substance by sharp short stresses that call into action its most intimate structural qualities. While it is wise, no doubt, to refrain from resting too much on these early results of relatively new and radical lines of inquiry, until their results shall be more mature, their prospective import is radical and decisive in favor of a solid earth not only, but of an elastico-rigid earth. Assuming that the present import of these inquiries will be amply justified by more mature research, it is pertinent to bring into consideration the corollary they so distinctly imply, viz.: that the molten and viscous material in the earth, or at least in its outer half, if not throughout

its deep interior, is negligible in general studies, and enters into general terrestrial mechanics only as a subsidiary feature. It seems necessary to limit liquid and viscous lacunæ—if there are lacunæ in any proper sense at all—to such moderate dimensions that they do not seriously kill out distortional waves passing through the outer half of the globe in various directions; for seismic instruments show that these waves retain their integrity with surprising tenacity through long traverses. It seems equally necessary to limit the liquid and viscous factor rather severely if the interior structure is to be consistent with so prompt a response of the earth to twelve-hour stress-pulses as to imply almost complete elastic fidelity.

In the light of these determinations, strengthened not a little by their concurrence with the later geological determinations, the working hypotheses of the earth-student can scarcely fail to give precedence to dynamic tenets founded on a rigid earth.

The limitation of liquid and viscous matter, thus imposed, quite radically conditions all tenable views of magmas and of vulcanism, and thus bears upon the igneous nature of the interior. No small part of petrologic effort in past decades has been spent on the differentiation of magmas. To a notable degree these efforts have proceeded on the assumption, conscious or unconscious, that differentiation took its departure from an original homogeneous magma such as might arise from residual portions of a molten earth. Indefinite lapses of time, and such conditions of quiet as are naturally assignable to residual reservoirs of lava, have been freely assumed as working conditions without much question as to their reality. Under the hypothesis of a molten earth passing slowly into a partially solid earth, and retaining residual lacunæ of molten matter as an incident of the change, these assumptions are quite natural. On the other hand, under the hypothesis of a pervasively rigid earth, affected by stress-conditions that are constantly varying in intensity and in distribution—and subject to more radical changes at times of periodic readjustment—the existence of such residual magmas becomes at least questionable, perhaps improbable. Still more questionable is the assumption that the multitude of little liquid spots supposed to arise within the elastico-rigid mass, always have conformed to one type or set of types. The inherent proba-

bilities of the case seem to point strongly to wide variation in nature due to selective solution or differential fusion. The liquefying action that brings magmas into being, under this view, is presumably controlled by the same chemical and physical principles as the solidifying phases of the same cycle. The logical presumption is that at all stages of a magma's career from its inception through its growth, climax and decline to its final solidification, selective action will be in progress more or less and that no stage will be entitled to be regarded as original or parental in a special sense, such a sense for example as might be appropriate if the lava were the residue of an inherited original state and were merely differentiated by fractional crystallization as it passed toward solidification.

While these contrasted views of the history of magmas are naturally connected with views of the genesis of the earth, they are not limited to this relation. They are inherent in the very relations of solid and liquid matter and have a more or less important place irrespective of the earth's genesis.

An element of no small importance to a revised concept of the interior of the earth has arisen from geodetic studies on the distribution of densities within the earth. As the geodetic point of view is to be presented by its foremost exponent, Dr. Hayford, it is permissible for me merely to refer to certain geologic bearings.

On the assumption that the earth was once in a molten state, the inference is unavoidable that a perfect state of isostatic equilibrium was originally assumed by the surface, and that its configuration was at first strictly spheroidal. The material must have been arranged in concentric layers according to specific gravity and each layer should have had the same density at every point. All such reliefs of the earth's surface, and all such differences of specific gravity in the same horizon as have since arisen, must have been superinduced upon this originally perfect isostatic surface. With good reason therefore these inequalities have heretofore been supposed to be relatively shallow. On the hypothesis that the earth grew up by heterogeneous accretions, it is an equally natural inference that differences of specific gravity extend to great depths. In an endeavor to find out the bearings of geodetic data on the distribution of densities, Dr. Hayford tested four assumptions, all of

which he found measurably compatible with his geodetic data. From these he derived the respective depths of 37, 76, 109 and 179 miles as the horizons to which differences of density extended and below which they vanished or became negligible. Now all these depths are greater than had been assigned for probable differentiation in the traditional molten earth. On the other hand, the highest figure, 179 miles, was derived from a curve drawn specifically to represent the probable distribution of densities in an earth of planetesimal growth. The distribution represented by this highest figure fits the geodetic data quite as well as either of the other assumptions of distribution, though drawn on a strictly naturalistic basis If it could be said that geodetic data demonstrate that the actual differentiation of specific gravities has its sensible limits somewhere between 37 and 179 miles below the surface, such considerable depth would distinctly favor an accretionary origin as against a molten origin. But a conclusive determination is yet to be reached by geodetic inquiries.

While it is possible, within the broad terms of the planetesimal hypothesis, to suppose that the rate of accretion was so fast as to give rise to a molten planet, such a result seems to me extremely improbable under the actual conditions of the case. The growing planet should have become capable of holding a considerable atmosphere by the time it attained one tenth of its present mass, *i. e.*, about the mass of Mars. After this the protective cushion of the atmosphere should have greatly checked the plunge of the planetesimals and largely dissipated them into dust in the upper atmosphere where the inevitable heat of impact would be promptly radiated away. The dust presumably floated long and came gently to earth, so that, while the total heat generated by impact was large, the temperature of the earth body was probable never very high during the later stages of growth, and perhaps not at any stage of growth. Following out as well as may be the probable rates and conditions of growth, the most tenable concept of the state of the earth's interior under the planetesimal hypothesis is as follows:

The condition of the nuclear portion supposed to be formed from one of the knots of the parent spiral nebula and constituting a minor fraction of the mass of the earth, say thirty or forty per cent., is

left indeterminate by present lack of knowledge of the physical state of the knots of spiral nebulæ. If these are gaseous—which is rendered doubtful by their lack of strict sphericity—the nucleus was doubtless originally molten. If the constituents of the knot were held in orbital relations, their aggregation might have been slow enough to permit a solid state of even this portion. The matter added to the nucleus as planetesimal dust, or as planetesimals reduced in mass and speed by the atmosphere, probably retained its solid condition, with negligible exceptions, throughout the process of accretion except as selected portions passed into the liquid state and became subject to extrusive action. An intimate heterogeneity naturally prevailed throughout the whole mass so aggregated. A selective process, however, probably brought in the heavier matter faster and earlier than the lighter matter, for the magnetism of the earth should have aided gravity in gathering in the magnetic metals while the inelastic planetesimals, predominantly the heavy basic ones, when in collision destroyed the opposing components of their motions and hence yielded to the earth's gravity sooner than the more elastic ones. Relatively high specific gravity in the material of the deep interior is thought to have arisen at the outset and to have been increased by the selective vulcanism that came into action as growth proceeded. Special emphasis is laid on the *selective* nature of vulcanism under this hypothesis. The intimate mixture of planetesimals and planesesimal dust gave rise to a multitude of minute contacts between particles of different chemical and physical properties and hence there arose wide differences in the solution points. As the temperature in the growing planet rose, the more soluble portions passed into the liquid state by stages long before the remaining larger portion reached the temperature of solution. In a stressed globe certain of whose stresses are more intense toward the center than toward the surface, the solutions worked in the direction of least resistance, for them generally outwards, carrying heat of liquefaction and leaving the less soluble larger portion behind with temperatures inadequate for further liquefaction until there was a renewed accession of heat. The mechanism thus automatically tended to remove the most soluble constituents by progressive stages, while it tended to preserve the solid condition of the

main mass. The hypothesis thus supplies a working mechanism whose results fall into full accord with the states of the interior implied by tidal investigations and by seismic data, while the postulated distribution of specific gravities accords fairly well with geodetic determinations, as they now stand.

The adaptation of such an earth to isostatic adjustment can scarcely be more than hinted at here. The growth of the earth should have given it a concentric structure, while its highly distributive vulcanism, together with some of its deformative processes, should have given a vertical or radial structure, the two conjoining to give a natural tendency to prismatic or pyramidal divisions converging toward the center. The most powerful of all the deformative agencies, rotation, required for the adaptation of the earth to its changes of rate, such divisions of the earth-body as would respond most readily to depression in the polar and bulging in the equatorial tracts reciprocally. As urged elsewhere, this accommodation seems best met by three pyramidal sectors in each hemisphere with apices at the center and bases at the surface, the sectors in opposite hemispheres arranged alternately with one another. Very simple motions of these sectors on their apices at the earth's center would satisfy the larger demands of rotational distortion, while the sub-sectors into which these major sectors would naturally divide, as stresses required, would easily accommodate the nicer phases of adjustment. This primitive segmentation to meet rotational demands—which were most urgent during the stages of infall—furnished a mechanism suitable for the easement also of a portion of the deformational stresses that arose from other sources, among them gravitative stresses arising from loading and unloading by erosion and sedimentation. A gravitational adjustment by the wedging up and down and laterally of such sectors is thus offered tentatively as a working competitor to theories of adjustment by fluidal or quasi-fluidal undertow. The necessary brevity of this statement leaves this new hypothesis little more than a crude suggestion that gravitative adjustment (= isostasy) may perhaps take place as fully as the case requires in a highly rigid elastic earth without resort to flowage or even quasi-flowage.

The University of Chicago.

II.

CONSTITUTION OF THE INTERIOR OF THE EARTH AS INDICATED BY SEISMOLOGICAL INVESTIGATIONS.

By HARRY FIELDING REID.

(*Read April 24, 1915.*)

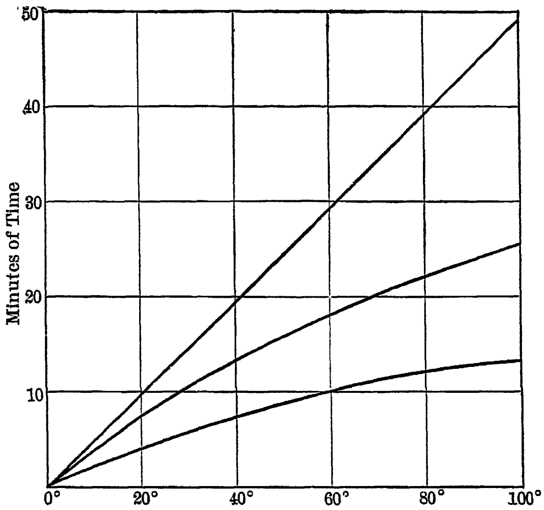
In 1883 Milne predicted that earthquake disturbances would be registered by seismographs at great distances from their origin, a prediction first verified when the earthquake of April 18, 1889, whose origin lay off the coast of Japan, affected the horizontal pendulum which von Rebeur-Paschwitz had set up at Potsdam to study the attraction of the moon. Milne was so convinced of the correctness of his idea and of the importance of the results to be obtained that in 1893 he established an observatory on the Isle of Wight to record earthquakes from distant regions; and he also succeeded in having instruments of similar model set up at observatories very widely scattered in various parts of the world.

Wertheim in 1851 showed that a disturbance in the interior of an elastic solid would break up into two groups of waves, longitudinal and transversal, which would be propagated at different rates, and as their velocities are so great that they cannot be separated from each other in the laboratory he suggested with rare insight that their separation might first be noticed in connection with the propagation of earthquake disturbances.[1] A few years later Lord Rayleigh showed that a third kind of wave could be propagated along the surface of the earth.[2] Seismologists naturally looked for indications of these three groups of waves in their

[1] "Sur la propagation du movement dans les corps solides et liquides," *Ann. de Chimie et Phys.*, 1851, Vol. XXI., p. 19.

[2] "On Waves Propagated along the Plane Surface of an Elastic Solid," *Proc. London Math. Soc.*, 1855, Vols. XLVII., L.

seismograms, but it was not until 1900 that Oldham succeeded in showing definitely that the seismograms of a number of Milne instruments gave clear evidence of the existence of three groups of waves. Oldham also published a diagram, which was an extension of Seebach's so-called "hodograph," showing the relation between the time of transmission of each group and the distance from the earthquake origin, measured along the surface of the earth. Milne soon improved these curves by adding observations of a large number of recorded shocks.[3] The general forms of the transmission curves are shown in the diagram. It will be seen that the curves



of the first and second "preliminary tremors," as Milne called the first two groups of waves, are curved, indicating that the velocity of transmission increases with the distance from the origin; a conclusion which had already been drawn from earlier, but less accurate, observations. Milne attempted to explain this by assuming that the path of the seismic disturbance lay along the chord and not along the earth's surface; this practically shortens the distance to the observing stations, and if the curves are plotted, with distances

[3] Rep. of the Com. on Seismol. Investig., B. A. A. S., 1902, p. 7.

measured along the chord, the curvature is considerably diminished; but later and more accurate observations show that even under this assumption the velocity still increases with the distance. The conclusion is unavoidable that as the path of the disturbance sinks deeper into the earth the velocity increases. The interior of the earth then is not a homogeneous but a refractive medium, and the path of the disturbance cannot be straight but must be curved with the concavity turned upward. This condition had been described by A. Schmidt as early as 1888.[4] Seismologists now believe that the three groups discovered by Oldham are respectively the longitudinal, the transverse and the surface waves. The transmission curve of the latter is a straight line indicating that the waves are transmitted with uniform velocity along the surface of the earth. They have affected seismographs after having passed completely around the earth. It cannot be said that the evidence, that the first two groups are respectively longitudinal and transverse, is complete; but it is sufficient, in connection with theory, to make seismologists fairly confident that the conclusion is correct; and the passage of transverse waves through the earth to great depths is proof that, to those depths, the earth is solid; for transverse waves cannot exist in a liquid. Further, since the velocity of transmission depends on the ratio of the elasticity to the density of the medium, and since both the longitudinal and transverse waves increase in velocity with the depth below the surface, both the elasticity of volume and the elasticity of figure of the earth, not only increase, but increase more rapidly than the density as we penetrate below the surface. The earth therefore is not only rigid, but its rigidity increases towards its center; though seismological evidence does not yet prove that this characteristic extends to the very center itself.

The next step was to determine the path of the waves in the earth and their velocity at different depths; the data for these determinations were the times of arrival of the earthquake waves at various distances from the origin; these times are collected in the transmission curves. At first sight this seems an insoluble problem;

[4] "Wellenbewegung und Erdbeben," *Jahreshefte für Vaterlands Naturkunde in Württemberg*, 1888, p. 248.

but, thanks to a remarkable mathematical theorem of Abel, it is not. It is clear that the time of arrival of an earthquake disturbance at a distant station will depend on the path followed and the velocity in different parts of the path, and if we make the reasonable assumption, which is borne out by observation, that the velocity is everywhere the same at the same depth, then it is evident, if the velocity increases continuously with the depth, that the transmission curves will be continuous without breaks, and their curvatures will nowhere make a sudden change. The mathematical solution of the problem has been obtained by Wiechert, Bateman and others, and concrete results have been obtained by Wiechert and his assistants, so that we now know the paths of the waves and their velocities with a fair degree of accuracy, at least to a considerable distance below the surface. But the questions arise: do the velocities increase continuously with the depth; and if so, how? questions which could be answered by the study of perfect transmission curves; but even imperfect curves yield some information; which, however, may be so faulty that it must be received with great caution. Milne, who has done such excellent pioneer work in seismology, was the first to propose and attempt to answer these questions.[5] He thought the transmission curve could be satisfied by supposing the earth to consist of a solid core having a radius of nineteen twentieths of the earth's radius, and surrounded by a thin shell. The core was of uniform density and elasticity, so that the velocity of propagation in it was uniform, and the paths of the rays would be straight lines. The velocity in the shell was much less than in the core. These conditions satisfied fairly well the very imperfect transmission curve of 1902, but they may be dismissed without further consideration, for such an earth could not satisfy the astronomic requirements, which exact, at the same time, the proper mean density and moment of inertia.

Benndorff in 1906 thought he found evidence of a central core of about four fifths the earth's radius, surrounded by two shells, the outer one having the same thickness as Milne's.[6] In the same

[5] Rep. of the Com. on Seismol. Investigation, B. A. A. S., 1903, p. 7.

[6] "Ueber die Art der Fortpflanzungsgeschwindigheit der Erdbebenwellen in Erdinnern," *Mitt. d. Erdbeben Com. k. Akad. Wiss. in Wien,* 1905, Nos. XXIX. and XXXI.

year Oldham deduced from the transmission curves a central core of not more than four tenths the earth's radius in which the velocity was distinctly less than in the surrounding shell.[7] Neither of these arrangements have been shown to conform to the astronomic requirements. Oldham's conclusions are based on what he considers a distinct break in the transmission curve of the transverse waves at distances between 120° and 150° from the origin; but when we remember that fully 95 per cent. of the energy of an earthquake shock comes to the surface within the hemisphere having the origin as its pole, we see that the data for great distances must be too imperfect to yield very reliable deductions.

Many years ago Roche showed that it was quite possible to determine a distribution of density in the earth which would be discontinuous at several levels, but which would still be astronomically satisfactory. Wiechert, in 1897,[8] showed that such a system might consist of a central core of radius about 4,900 km. or three fourths of the earth's radius, consisting of iron with a density of about 8.3, surrounded by a stony shell about 1,500 km. thick and with density varying from 3 to 3.4. It was natural that he should examine the transmission curves to see if they supported his ideas; and at the Hague meeting of the International Seismological Association in 1907 he announced that they did. At the Manchester meeting of the same association in 1911 he announced the existence of two shells around the central core. In 1914 Gutenberg (one of Wiechert's assistants) announced the existence of three shells.[9] In addition to ordinary times of transmission, Gutenberg also used the times of waves reflected at the earth's surface and the variations in the amplitude; it is evident that a wave which crosses the boundary of the core will experience reflection and refraction; and whichever part is later observed at the surface of the earth will have a dis-

[7] Constitution of the Interior of the Earth, *Quart. Jour. Geol. Soc.*, 1906, Vol. LXII., p. 456.

[8] "Ueber die Massenvertheilung im Innern der Erde," *Nachr. k. Gesells. Wiss. Göttingen*, 1897; *Math.-phys. Kl.*, p. 221.

[9] "Ueber Erdbebenwellen," VIIA. *Nach. k. Gesells. Wiss. Göttingen; Math.-phys. Kl.*, 1914, p. 1; references to the earlier numbers of the series are given in this paper.

tinctly smaller amplitude than the wave which just missed penetrating into the core. The following table shows the positions of the boundaries of the shells and of the core, and the velocities of the longitudinal waves *P* and of the transverse waves *S;* it will be noticed that it is only at the boundary of the central core that any marked sudden change in velocity occurs.

Depth, kms.	Veloc. km./sec. *P.*	*S.*
0	7.17	4.01
1200	11.80	6.59
1700	12.22	6.86
2450	{ 13.29 13.15	{ 7.32 7.20
2900	{ 13.15 8.50	{ 7.20 4.72
6370	11.10	6.15

The remark regarding Oldham's results applies also here, namely that it is questionable whether the observations at distances greater than 100° or 120° are sufficiently accurate to justify such definite conclusions. Gutenberg had the advantage, however, of more accurate observations than Oldham, and also of measures of amplitudes. There is no *a priori* reason why the earth might not be made up of a number of shells, but there should be satisfactory evidence for any proposed system; and it must be shown to satisfy the astronomic requirements; or, at least, not to contradict them. Gutenberg's system does not correspond with Wiechert's system of 1897. In the latter a marked change in physical properties occurs at a depth of 1,500 km.; in the former, at a depth of 2,900 km.; and in crossing into the core, the ratio of the elasticity to the density, according to Gutenberg, rapidly loses six tenths of its value. This change might be the result of a great increase in density or a great decrease in elasticity; it may be questioned whether the former is compatible with the astronomic requirements, and whether the latter is compatible with the high rigidity which we know the earth, as a whole, has. So far no answer has been given to these questions.

In 1879 George and Horace Darwin attempted to determine the rigidity of the earth by measuring the deviation of the vertical under

the attraction of the moon. If the earth yielded like a fluid, its surface would always remain at right angles to the vertical, and a pendulum would remain relatively stationary for all positions of the moon; if the earth were absolutely rigid, the moon's attraction would deflect the pendulum an extremely small amount, but an amount capable of being measured. The Darwins did not obtain definite results because the disturbances of their pendulum were greater than the deflections they attempted to determine.

A little later von Rebeur-Paschwitz attacked the same problem with better success, using a horizontal pendulum.

Hecker, in Potsdam, and Orloff, in Dorpat, have repeated von Rebeur-Paschwitz's experiment; and both found values for the average rigidity of the earth comparable with that of steel. But, what was most remarkable and what is still unexplained, the rigidity was apparently greater in an east-west than in a north-south direction. Orloff, experimenting at a greater distance from the ocean, found a smaller difference than Hecker did, and it has been suggested that the tides of the ocean are the cause of the difference. The International Seismological Association, at its Manchester meeting in 1911, made plans to repeat the experiments in Paris, in central Canada, in the middle of Southern Africa and in the middle of Russia; but no reports have yet come from these stations.

In the autumn of 1913, Michelson attacked the same problem by a new method, which seems capable of yielding more accurate results than the horizontal pendulum. He measured the deflection of the vertical under the influence of the moon by what was practically a water level 500 feet long, sunk six feet in the earth.[10] Michelson's results for the E-W rigidity do not differ greatly from those of Orloff; but his N-S rigidity is somewhat less than Orloff's. Michelson's experiments also show that the viscosity of the earth must be as great as that of steel. These experiments are of great interest; they should be repeated at various places, and especially at places symmetrically situated with respect to the great oceans, and on mid-oceanic islands, in order to determine how far they are affected by the oceanic tides.

[10] "Preliminary Results of Measurements of the Rigidity of the Earth," *The Astrophysical Journal*, 1914, Vol. XXXIX., p. 97.

We can say in conclusion, that the transmission of transverse earthquake waves shows that the earth is solid, at least to a great depth below the surface; and that experiments on the deflection of the vertical show that it is quite as rigid and as viscous as steel. There are still difficulties in the interpretation of the observations, but their elucidation cannot alter the general character of the conclusions.

III.

THE EARTH FROM THE GEOPHYSICAL STANDPOINT.

By JOHN F. HAYFORD.

(*Read April 24, 1915.*)

This is a broad topic on which much intensive thinking has been done by many men: It is impossible to treat it adequately or comprehensively in the short time available.

In this address an attempt will be made to so concentrate attention on a certain few points as to tend to clarify existing ideas and to correlate them. An attempt will also be made to help in locating the lines of least resistance to future progress in the study of the earth.

The size of the earth, as well as its shape, is now known with such a high degree of accuracy that the errors are negligible in comparison with the errors in other parts of our knowledge of the earth. The probable error of the equatorial radius is less than 1/300000 part, and of the polar semi-diameter is about the same.

The three physical constants of the earth, and of its different parts, on which you are now asked to concentrate your attention are the density, the modulus of elasticity, and the strength.

It is important to know as much as possible about the density. The more one knows about the density in all parts of the earth the more surely and safely one may proceed in learning other things about the earth.

The modulus of elasticity at each point in the earth controls the behavior of the earth under relatively small applied forces.

The strength of the earth, at each point, as measured by the stress-difference at that point necessary to produce either slow continuous change of shape or rupture, decides the behavior of the earth under the greater forces applied to it.

As to density we know that the earth's surface density is about

2.7, that the density probably increases continuously with increase of depth, that the density at the center is probably about 11, that the mean density is about 5.6, and that within a film at the surface of a thickness of about one fiftieth of the radius of the earth there is isostatic compensation which is nearly complete and perfect as between areas of large extent.

The manner of distribution of the isostatic compensation with respect to depth, and the limiting depth to which it extends are but imperfectly known. Nevertheless it appears that above the depth, 122 kilometers, the compensation is nearly complete even though there may be some compensation extending beyond that depth.

Two general lines of evidence are available in determining the modulus of elasticity of the earth, that from earthquake waves, and that from earth tides.

There are many inherent and extreme difficulties in the way of securing reliable evidence as to the modulus of elasticity from earthquake waves.

To 1913 the accuracy of available observations of tides in the solid earth was insufficient to furnish a basis for reliable conclusions. Nevertheless the estimates of the modulus derived from these early observations were a fair approximation to that given by the very recent and much more accurate observations.

Dr. Michelson and those associated with him in the observation of earth tides at the Yerkes Observatory since 1913 have developed a method of observing which is of a new order of accuracy such that the minute changes of inclination at a given point due to earth tides may be determined with an error of less than one per cent.

These observations make the modulus of elasticity of the earth as a whole about like that of solid steel, namely (8.6) (10^{11} C.G.S.).

It is the modulus of elasticity of the earth as a whole which is measured in this case.

It is eminently desirable to determine if possible whether the modulus of elasticity varies with increase of depth. The Michelson apparatus possibly opens the way to such a determination. Suppose that the apparatus is used on the shore of the Bay of Fundy. Twice a day a large excess load of water is placed in the bay by the tidal oscillation and as frequently the water load is reduced below

normal. The stresses produced in the body of the earth by these changes of load applied over an area only about 30 miles wide are probably confined almost entirely to the first 100 miles of depth. The magnitude of changes of inclination produced at an observing station on the shore by the changing water load would, therefore, be dependent primarily on the modulus of elasticity of the material below and around the bay to a depth of less than 100 miles. The observations might serve, therefore, to determine a modulus of elasticity of the surface portion of the earth rather than of the whole earth.

Turn now to the third of the physical constants which it was proposed to examine, namely the strength.

Among the forces which we may consider as furnishing tests of strength are: (1) the forces involved in earthquakes, (2) the weight of continents, and (3) the weight of mountains.

The forces which produce the more intense earthquakes evidently cause stress-differences locally which are beyond the breaking strength of the material. However from earthquakes we may obtain but little information as to the strength of the earth material because the intensity of the stress-differences cannot be reliably determined. We know simply that the intensity exceeds the breaking strength of the material, at the points of rupture.

It is uncertain how great are the maximum stress-differences produced by the weight of continents. One great difficulty in computing these stress-differences arises from the fact that the isostatic compensation of continents, now known to exist, reduces the stress-differences much below what they would otherwise be. Love computed the maximum stress-differences thus reduced as .07 ton per square inch. Darwin computed the greatest stress-difference due to the weight of the continents, without isostatic compensation, as 4 tons per square inch. If each of these computations were based upon assumptions which correspond closely with the facts one should be warranted in drawing the conclusion that the maximum stress-difference caused by the actual continents supported in part by the actual isostastic compensation is between .07 and 4 tons per square inch, and that it is much nearer to the smaller than to the larger value. But a close examination of either of these computations shows that it is based

upon assumptions made to simplify and shorten the computations, which assumptions depart widely from the facts and tend strongly to make the computed stress-differences much smaller than the actual. For example, both Darwin and Love used in their computations hypothetical continents represented by regular mathematical forms in the place of the actual continents with their many irregularities. The maximum stress-difference caused by the actual continents is necessarily much greater than would be produced by the assumed smoothed out, regular, symmetrical continents.

Similarly, no adequate computations have been made to determine the maximum stress-difference due to the mountains. Darwin computed the maximum stress-difference produced by two parallel mountain ranges, of density 2.8, rising 13,000 feet above the intermediate valley bottom, to be 2.6 tons per square inch. Love, for the same mountain ranges, but with isostatic compensation taken into account, computed the maximum stress-difference to be 1.6 tons per square inch. In this case the computation indicates that the isostatic compensation reduced the maximum stress-difference to but little more than one half what it would otherwise be. Here again both the computed maximum stress-differences have been greatly reduced by substituting hypothetical smoothed-out mountains in the place of the actual irregular unsymmetrical mountains.

To the person who is trying to get a true picture of the present state of stress in the earth, two very important facts are made evident by a comparison of the Love and the Darwin computations. First, the existence of isostatic computation greatly reduces the stress-differences which would otherwise be produced by the weight of the continents and mountains. Second, the depth at which the maximum stress-difference tends to occur is evidently very much less with isostatic compensation than without it. These two conclusions, based on the differences between the two computations, are apparently reasonably safe even in spite of the same wild assumptions on which both the computations were based.

Note that even a little information as to the distribution of densities—a little information about isostatic compensation—profoundly modifies the conclusions as to the state of stress in the earth. It should, therefore, be clear why it was so emphatically stated in

an earlier part of this address that information as to the distribution of density in the earth is necessary in order to make safe progress in learning other things about the earth.

Is the earth competent to withstand without slow yielding the stress-differences due to the weight of continents and mountains, the isostatic compensations being considered? From the computations by Darwin and Love, considered in the light of the assumptions made by them to simplify the computations, I estimate that it is probable that the actual mountains and continents with all their irregularities of shape and elevation possibly produce stress-differences in some few places as great as four tons per square inch, and certainly produce stress-differences at many places as great as two tenths of a ton per square inch. The material would certainly yield slowly under such stress-differences especially when they persist continuously over long periods of time and throughout large regions. Four tons per inch is the breaking or rupture load for good granite, one of the strongest materials existing in the earth in large quantities. Two tenths of a ton per square inch is the safe working load used by engineers for good granite. There is abundant evidence from laboratory tests that the so-called yield point on which the engineer bases his estimate of safe working load for a given material is a function of the length of time the load is applied and the delicacy of the test. The longer the time of application and the more refined the test to determine the permanent yield the lower the observed yield point. In the case of the test in progress in the earth the time of application is indefinitely long and the test is extremely refined inasmuch as the minimum rate of yielding which may be detected is exceedingly small.

If an engineer wishes to know whether a bridge, or foundation, or building, or railroad rail is yielding under stress-differences which have been brought to bear upon it he looks for evidence of distress, for rivet heads popped off, scaling from the surface, settling, cracks, or even changes in microscopic structure. The geologists have made very extensive corresponding examinations of the earth. Everywhere they find evidence that the earth has yielded. On the one fourth of the earth's surface exposed to examination, the land, there is no part for which the evidence does not indicate

past uplift, or subsistence, or horizontal thrust, or cracking under tension, or cracking produced by shear, or microscopic yielding in detail such as produces schistosity for example, or some other form of past yielding to stress-differences. The physicist studying the earth must take this overwhelming mass of evidence into account and must conclude that the earth habitually yields slowly to the stress-differences brought to bear upon it. Please note that I do not assert that the stress-differences are all due to gravity.

I propose now to state what are in my opinion probably the lines of least resistance to future progress in studying the earth from the physical standpoint. I propose to outline what I believe to be the most effective methods of attack, and to indicate some of the conclusions which will probably be reached. I am led to this procedure by two considerations. First, I find it possible to state certain of my opinions as to the net outcome of past investigations most clearly in that form—and time presses. Second, I indulge the hope that such an outline which is frankly an expression of judgment based on evidence much too weak and conflicting to be proof, may possibly kindle the imagination of some man or men, and so lead to vigorous attacks upon the problem and to future progress.

In attacking the problems of the earth one should assume at the outset that the phenomena exhibited are very complicated, that they are probably due to various simultaneous actions, and that the various actions are probably closely interlocked, modifying each other, though some are probably primary in importance and others secondary. Hence the most effective method of attack is probably one which includes a general correlation of apparently widely separated ideas and facts gathered from physicists, engineers, geologists, chemists, etc., and at the same time includes intensive attacks in detail on one after the other of single features of the problems which arise and an intensive working out of the possible consequences of said features.

It should be recognized at the outset that no observed behavior of the earth clearly warrants the assumption that the material of which it is composed differs radically in any way from that accesible at the surface. It should be assumed, therefore, that throughout the earth the materials are a mixture differing from the mixture

found at the surface only as the extreme pressure and temperature conditions at great depths directly and indirectly produce differences.

It should be kept clearly in mind that the geodetic evidence from observations of the direction and intensity of gravity indicates simply the present location of attracting masses, the present distribution of density. It furnishes no direct evidence whatever as to past distributions of density, or as to changes in density now in progress. But an understanding of the present distribution of density within the earth, especially near the surface, is so necessary to a true understanding of the present state of stress and of viscous flow in the earth that an understanding of the geodetic evidence is fundamental to progress.

Computations should be made in extension of those which have been made by Darwin and Love. The new computations should, however, deal with the actual irregular continents and mountains, not with regular substitutes. The computations should also take into account the bulk modulus of the materials composing the earth, that is these materials should be assumed to be compressible. Such computations will no doubt be both difficult and long. I believe that even a moderately vigorous attack along this line will show conclusively that the earth does not behave as an elastic body under the large loads superimposed upon it by the continents and mountains. I believe that the computed stress-differences will be found to be so large that the computation will be essentially a proof of viscous yielding.

Next make the contrasting assumption that the material composing the earth is competent to withstand but little shearing stress, and that the pressure at any point is that due to gravitation acting on the mass in the column extending from the point vertically to the surface. Let it be assumed that isostatic compensation exists, is uniformly distributed with respect to depth, and is complete at depth 122 kilometers. Consider the actual topography and form a mental picture as accurately as possible of the viscous flows which would take place on the assumption that at each level the material would flow horizontally from regions of greater pressure to regions of less pressure along lines of maximum rate of change of pressure, and that the time rate of such viscous flows would tend to be pro-

portional to the space rate of change of pressure. The flows would all be found to be away from beneath high regions toward low regions, from continents toward oceans, from mountains toward valleys.

After such a picture has been clearly formed assume that the isostatic condition is disturbed by long-continued erosion and deposition producing changes in the surface elevations and surface loads. On the same assumptions as to the nature of the viscous flows as before, form a new picture of the viscous flows which would now be in progress. It will be found that under the new conditions the viscous flows near the surface would still be away from high areas and toward low areas, but in general they would be slower than before. At greater depths, however, it will be found that the viscous flows would be undertows from regions of recent deposition toward regions of recent erosion. These undertow flows would in general tend to be in the direction opposite to recent surface transportation of material. This picture would serve as a first approximation to an understanding of the mechanism of isostatic readjustment. The undertows would be found on these assumptions to extend to a considerable depth, certainly more than 122 kilometers.

Next one should picture the changes in density which would be produced by the viscous flows. The density should be pictured as decreasing in regions from which material is being carried away by the flow and increasing in regions to which the material is being carried. It will be noticed as soon as such a picture is formed that every undertow flow at any level tends to equalize pressures at lower levels. This will have a strong tendency to make the prevailing undertows occur at much higher levels than they otherwise would.

Let it be assumed that the viscous material offers some small resistance to shear and still has elastic properties to a slight degree. The condition assumed originally that the pressure at a point depends simply upon the weight of the material above that point will be disturbed thereby. Form as clear a conception as possible of these disturbances and the modifications of the flows produced by them. I believe the modifications will be found to be important, and that they will be found to be such as tend to confine the effects of surface changes of load to a depth which is a small fraction of the radius.

So much for the direct effects of gravity which it seems important to picture clearly. Next study other effects, some of which are indirectly produced by gravity.

First study the modifying effects of changes of temperature. Wherever viscous flow takes place in the quasi-solid portions of the earth there heat is necessarily developed in amount equivalent to the mechanical energy expended in overcoming the resistance to flow. This will tend to increase the volume of the material, to increase the pressure, and to raise the surface above the region of viscous flow. It is probable also that the increase of temperature will tend to weaken the material, thus emphasizing the weakening produced by the damaging mechanical effects of the flow.

This temperature effect is probably locally important.

Beneath areas of recent deposition the temperature of a given part of the buried material will slowly increase for long periods of time, on account of heat conducted up from below and prevented by the new blanket of deposited material from rising to the surface so freely as before. Conversely, beneath the areas of recent erosion the temperature of a given portion of material will decrease. The ultimate limit of change will tend to be in each case not greater than about one degree Centigrade for each thirty-two meters of depth of erosion or deposition. These temperature changes tend ultimately to lower areas of recent erosion and to raise areas of recent deposition, possibly as much as one thirtieth of the thickness of the erosion or deposition,—the temperature effect taking place much later than the erosion or deposition which initiated it.

Study next the effects which may be computed from the bulk modulus of elasticity. Beneath areas of erosion a given particle of matter tends to rise by an amount which may be computed from the bulk modulus of material, and similarly a particle tends to fall beneath an area of deposition. If the depth to which the elastic phenomena extend is as great as 122 kilometers and the bulk modulus is 500,000 kilograms per square centimeter (corresponding to granite) the rise or fall of a particle near the surface will tend to be at least 1/50th part as great as the thickness of the material eroded or deposited. This is a change so large as to have considerable effects in modifying or magnifying the actions which would

otherwise occur. Possibly this elastic change is much larger than the estimate here given. Of course if the erosion or deposition takes place in a small area only, such elastic response will be largely inhibited by surrounding material on which the load has not been directly changed. But under large areas of erosion or deposition such action must take place and extend to depths possibly as great as 122 kilometers.

Study next the modifying effects, on the phenomena already pictured, of chemical changes which are probably produced in the earth by changes of pressure. The expression "chemical changes" is here used in the broadest possible sense. A relief of pressure at any given point in the earth necessarily favors such chemical changes as are accompanied by increase in volume and reduction of density. Increase of pressure tends to have the reverse effect. Such changes tend to reinforce and extend in time the effects just referred to which may be computed from the bulk modulus of elasticity. It is important to estimate such changes as well as possible from all available evidence, such for example as that furnished by chemists, by geologists, and by such investigations of rock formation as have been conducted at the geophysical laboratory in Washington. I believe the possible effects of this kind will be found to be so large as to be of primary importance.

Evidence has accumulated during the past few years which makes it reasonably certain that with increased pressure, as at the great depths in the earth, the rigidity and the viscosity of the material also necessarily increase. This tends to cause the viscous flows to take place at higher levels than they otherwise would. This should be taken into account.

Next a reëxamination of the conceptions so far formed should be made to ascertain to what extent and how they would be modified if one started with some other reasonable assumption as to the limiting depth of present isostatic compensation or some other reasonable assumption as to the law of distribution of the compensation with regard to depth.

Next full and extensive comparisons should be made between the hypothetical phenomena on the one hand pictured as made up primarily of viscous flows, modified by some elastic effects, ini-

tiated in part by surface transfers of load, modified by changes of temperature, modified by chemical changes and in the other ways, and on the other hand the facts of the past as to the behavior of the earth recorded in the rocks and read by geologists and others. This comparison should be used to the fullest possible extent to evaluate the relative importance of the various elements in the actions.

In making this comparison of various hypothetical phenomena with the great accumulated mass of geological facts it should be recognized at once that it is false logic to reason that if a given hypothesis does not account for all the observed facts the hypothesis is necessarily erroneous. On the contrary it is true logic in dealing with such a problem as the earth seen from a physical standpoint to reason that the more facts are accounted for by a given hypothesis the more certain it is that said hypothesis is a statement of a controlling element in the complex phenomena and then to study the facts which appear neutral, or conflicting, with reference to the hypothesis, considering them as indicators of other elements of the phenomena which one should attempt to embody in other supplementary hypotheses.

I submit that in studying the earth it is a mistake to think that there is any necessary conflict between the idea that the earth behaves as an elastic body and the idea that it is yielding in a viscous manner. A body may behave in both ways at once. The earth is probably acting largely as an elastic body under small forces which change rapidly and at the same time is yielding in a viscous manner to forces of larger intensity which are applied in one sense continuously for long periods.

The object of this address will have been accomplished if it serves in time to arouse the imagination and interest of some one and to guide him to greater effectiveness in attacking the problems presented by the earth as seen from the geophysical standpoint.

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MORPHOLOGY AND DEVELOPMENT OF AGARICUS RODMANI

(PLATES VII.–XIII.)

BY GEO. F. ATKINSON.

(*Read April 23, 1915.*)

INTRODUCTION.

Agaricus rodmani[1] was described by Peck in 1885, from specimens growing in "grassy ground and paved gutters" at Astoria, Long Island. As to its habitat and occurrence a more specific statement is made in 1897, in that it "grows in grassy ground and even in crevices of unused pavements and paved gutters in cities,"[2] from May to July, and is said to be rare. It has been observed in the city of Ithaca, N. Y., for a number of years, where it is usually found growing in the parking between the sidewalks and street curbing, or even in the crevices of stone paved streets and gutters, and also in grassy ground along the street railway or along walks on the border of groves. The material for this study was collected in August, 1914, along the Ithaca street railway and by the side of paths along the border of groves on the campus. In these places the mycelium in spots was often very abundant so that lumps of soil resembling a fine quality of spawn were exposed in digging for the young stages. The young fruit bodies collected were scattered on these cords of mycelium, the material and conditions offering very clear evidence of the normal development of the basidiocarps. The material was fixed in chrom-acetic fluid and sectioned in paraffin.

The features of interest in the morphology and development of *Agaricus rodmani* which I have considered in the present study are as follows: (1) the duplex character of the annulus, or ring, on the stem, and its significance; (2) the origin of the hymenophore funda-

[1] N. Y. State Mus. Nat. Hist. Rept., 36, 45, 1885.

[2] N. Y. State Mus. Nat. Hist. Rept., 48, 139, 1897.

ment; (3) the differentiation of parts in the primordial ground tissue; and (4) the origin and development of the lamellæ. The peculiar form and position of the annulus on the stem has suggested a resemblance to a volva, a structure not admitted in the genus *Agaricus* as now limited; while the subject of the origin and development of the lamellæ has acquired new interest in all of the Agaricaceæ since the accuracy of observations and the correctness of the statements covering a period of more than a half a century, in regard to this topic, have recently been called in question. Without further preliminary remarks we may proceed to an account of the present investigation, and to a consideration of the various matters involved.

I. The Duplex Annulus and its Significance.

The Annulus.—The annulus is situated near the middle of the short stem, or even near its base. It is usually very thick next the stem and is divided into an upper and lower limb by a deep marginal groove as is clearly seen in the photographs reproduced in Plate I. In those cases where the annulus is near the base of the stem, Peck was impressed by its suggestion of "the idea of a volva" (*l. c.*, 45). Before the expansion of the pileus, while the veil is still attached to the stem and pileus margin, a longitudinal section of the plant shows very clearly that the lower limb of the annulus lies on the outer (upper) side of the pileus margin (see Plate VII., upper right hand and lower left hand figures). The marginal veil is very thick and the epinastic growth of the pileus margin crowds the latter into the veil tissue and against the stem. The position of the lower limb of the annulus therefore corresponds to that of the volva limb of the *Amanitas*.

The plates represented in the upper group of Plate VII., were collected on the Cornell University campus, those in the upper group during August, 1911, along a path in the edge of a small wood not far from the street; those in the lower group, July, 1913, along the street railway and parking by East Avenue. In the expanded specimens, the pileus ranged from 6 cm. to 8 cm. in diameter. The plants were smaller than those represented in Plate VIII., but since they were abundant and in all stages of development they present in

an excellent way the different details of the veil and annulus during expansion of the plant. Those represented in Plate VIII., were collected by Mr. Wood, June 28, 1915, in the parking between the sidewalk and street, on Stewart Avenue, in front of the Town and Gown Club, Ithaca, N. Y. They were very robust specimens, and show the great distance between the upper and lower limb of the annulus. They are reproduced here real size.

A thin outer layer of the lower limb of the annulus is continuous below with the outer layer of the stem, and also with a very thin surface layer of the pileus. As the stem elongates at the time of the expansion of the plant, this outer layer of the stem lags behind and is thus torn into irregular patches shown very clearly in the two upper left-hand figures of Plate VII. The edges of these patches are frequently warped away from the stem, thus showing a tendency to exfoliation. This is especially marked in the case of the surface layer of the stem next the lower limb of the annulus. The warping upward of this layer, after it has been severed from its connection below, often gives the appearance of a double edge to the lower limb of the annulus, as shown in the lower right-hand figure of Plate VII., where the upper limb of the annulus has not yet broken away from the pileus margin.

The very thin layer on the pileus which is also continuous with a thin outer layer of the lower limb of the annulus often shows a tendency to exfoliation. This partial exfoliation of the stem and pileus surface is clearly marked where the basidiocarps are somewhat soiled by contact with particles of earth, as they are likely to be during the period of subterranean growth.

The outer portion of the lower limb of the annulus, as well as the corresponding thin, and partially exfoliating surface layer of the pileus and stem are derived from the outer layer of the blematogen. The blematogen layer, as I have interpreted it, is present in the genus *Agaricus* as well as in *Amanita*. In the species of *Amanita* thus far studied,[3] the blematogen at length is clearly separated from the pileus by a cleavage layer, arising from the gelatinization, or other kind of disintegration, of the external layer of the pileus primordium, thus

[3] Atkinson, Geo. F., "The Development of *Amanitopsis vaginata*," *Ann. Myc.*, 12, 369–392, pls. 17–19, 1914.

giving rise to the teleoblem, or finished volva. But in the genus *Agaricus*[4] no such cleavage layer is formed, and the surface of the pileus primordium becomes consolidated with the blematogen layer which here does not form a true volva, or teleoblem.

The lower limb of the annulus of *Agaricus rodmani* is not, therefore, strictly homologous with the volva of the *Amanitas,* not even including the thin layer of the stem and pileus which sometimes tends to peel off, since it does not comprise all of the blematogen layer, nor is it separated from the pileus by a distinct cleavage layer. If it were homologous with the volva of the *Amanitas,* then this species would represent a generic type distinct from *Agaricus* (*Psalliota*). In fact other species of *Agaricus* frequently show a similar condition of the annulus, *i. e.,* where the margin is "grooved," due to the inset of the pileus margin into the veil where the conditions for the robust development of the veil are favorable. In *Agaricus campestris* the annulus frequenlty presents a grooved margin, not only in the case of cultivated forms, but more rarely in the feral state. This condition is well shown in Plates 11 and 12 of my article on *Agaricus campestris.*[5] In Fig. 20 of that article the lower limb of the annulus has broken away from the outer surface of the incurved pileus margin, while the upper limb is still attached to the edge of the pileus. In Figs. 18 and 19 the upper limb has also become freed from the pileus margin and the grooved character of the edge of the annulus is very distinctly shown. In Fig. 15 of the same article, sections of the young basidiocarps show very clearly the position of the lower limb of the annulus extending over the outer (upper) side of the pileus margin. Fig. 20 also shows very clearly that the annulus as a whole is ripped off from the lower part of the stem, being an exaggerated case of the slight peeling up of the thin surface layer of the stem mentioned above in *Agaricus rodmani.* That the

[4] Atkinson, Geo. F, "The Development of *Agaricus arvensis* and *A. comtulus,*" *Am. Jour. Bot.,* 1, 3–22, pls. 1, 2, 1914.

Atkinson, Geo. F., "Homology of the Universal Veil in *Agaricus,*" *Myc. Centralb.,* 5, 13–19, pls. 1–3, 1914.

Atkinson, Geo. F., "The Development of *Lepiota clypeolaria, Ann. Myc.,* 12, 346–356, pls. 13–16, 1914.

[5] Atkinson, Geo. F., "The Development of *Agaricus campestris,*" *Bot. Gaz.,* 42: 241–264, pls. 7–12, 1906.

lower limb of the annulus in *A. rodmani* is merely a part of the marginal veil is clearly seen in the sectioned plants shown in the lower groups of Plate VII., where the connecting portion between the two limbs is clearly differentiated from the surface of the stem with which it is in contact, a situation very different from that in *Amanita* where the volva has no such relation to the annulus.

Comparison of Agaricus rodmani with other Species of Agaricus. —This extensive peeling, or ripping upward of the annulus from the lower part of the stem in *Agaricus campestris* is the cause of the more extensive, *i. e.*, broader, veil and annulus than is characteristic for *Agaricus rodmani.* Peck regards this species as intermediate between *Agaricus campestris* and *A. arvensis,*[6] resembling the former in size, shape and general appearance; the latter in the "whitish primary color of the lamellæ," in the occasional yellowish tints of the pileus, and the occasional rimose under surface of the annulus. The robust character of the annulus of *Agaricus rodmani* and the thick flesh of the pileus margin crowded by epinastic growth against the stem deepens and widens the groove on the edge of the annulus. This, together with the very short stem, in comparison with the longer stem of *Agaricus campestris* and *A. arvensis,* is, I think, largely responsible for certain differences in the character of the under surface of the annulus in the different species. In the species with the longer stem more stretching of the stem occurs and the annulus (or veil) is ripped upward from a greater extent of the stem surface. The radiately grooved character of the under surface of the annulus, in certain species (*A. arvensis* Schultz, *A. abruptibulbus* Pk., *A. placomyces* Pk., *A. hæmorrhoidarius* Schultz), or the coarsely floccose or scaly character in certain others (*Agaricus subrufescens* Pk., *A. augustus* Fr., or both features contained in some) is largely due to the fact that this part of the annulus is stripped from the stem and then brought under greater tension than the upper surface as the expansion of the pileus stretches the veil outward. All things considered *Agaricus rodmani* is much more closely related to *Agaricus campestris* than to any other of the species. It is very probably identical with *Agaricus campestris* var.

[6] N. Y. State Mus. Nat. Hist. Rept., 36, 45, 1885.

edulis Vitt.,[7] as I have elsewhere suggested[8] (1900, 1901, 1903, p. 20). Excellent figures of this variety are given by Vittadini (*l. c.*, pl. 6) and by Bresadola[9] (pl. 54).

II. Origin of the Hymenophore Primoridum

Primordium of the Basidiocarp.—The primordia of the basidiocarps are elliptical or oval in outline, and reach a diameter of 3 mm. or 4 mm. before there is any internal evidence of a differentiation of parts. The length is usually somewhat greater than the transverse diameter. In specimens not so well nourished differentiation may begin before the primordia have reached this size. The primordium, from the size of 2 mm. to 4 mm. in diameter, consists of a homogeneous interlacing of stout mycelial threads with rather thick walls. In primordia 3 mm. to 4 mm. in diameter the hyphae average about 5 μ to 7 μ in thickness, occasionally stouter ones are seen which measure up to 10 μ. More slender threads are also intermingled, but all sizes are so indiscriminately interwoven that no structural differentiation is perceptible. In smaller primordia the hyphæ average less in diameter. In most of the primordia examined, the sections are evenly stained throughout, but in a few a narrow zone a short distance from the surface stains more deeply than the external and internal tissue (Fig. 2). This suggested the possibility of a differentiation of an outer zone distinct from the bulk of the fruit body, which is sometimes present in *Agaricus campestris* and which I have called the *protoblem*.[10] A similar zone is found in some of the basidiocarps after the origin of the hymenophore fundament, but in the material which I have examined it is the exception rather than the rule, and I am inclined to the belief that it is due to some condition which affects the rate of growth or increase of cer-

[7] Vittadini, C., "Funghi Mangerecci," 44, 1835.

[8] Atkinson, Geo. F., "Studies of American Fungi; Mushrooms, Edible, Poisonous, etc.," 1st edition, I–VI., 1–275, 76 plates (223 figs.), Ithaca, N Y., 1900. *Idem,* 2d edition, I–VI., 1–322, 86 plates (250 figs.), Ithaca, N. Y. 1901. *Idem,* New York City, 1903.

[9] Bresadola, G., "Funghi Mangerecci e Velenosi," 1899.

[10] Atkinson, Geo. F., "The Development of *Agaricus arvensis* and *A. comtulus*," *Am. Jour. Bot.*, 1, 3–22, pls. 1, 2, 1914. "Homology of the Universal Veil in *Agaricus*," *Myc. Centralb.*, 5, 13–19, pls. 1–3, 1914.

tain individuals. A protoblem[11] is very likely present, but it is difficult to distinguish in primordia havng a subterranean origin because of the ease with which the delicate protoblem is removed while removing the soil, and especially in the forms and species of *Agaricus* with a white pileus. In those with a brown pileus, like *Agaricus campestris* var. *bohemia* of the commercial spawn growers, the delicate, white protoblem is very distinct.

Differentiation of an Internal Annular Hymenophore Primordium.—The first evidence of internal differentiation is the appearance of an internal annular zone of new growth in the region of the smaller end of the oval fruit body. This can be studied with advantage by means of serial, longitudinal sections. A median longitudinal section is shown in Fig. 3, while a "tangential" section, *i. e.*, parallel with the axis of the basidiocarp, but through one side of the annular zone of new growth is shown in Fig. 4. Diagrams 1 and 2 (in the text) show how the sections were made. Fig. 3 is from the region marked by the line 2, while Fig. 4 is from that marked by the lines 1 and 3. The darker staining areas in Figs. 3 and 4 mark the position of the zone of new growth. In the median

[11] The delicate, floccose, primary universal veil, or protoblem was observed by Fries on *Agaricus campestris* and a few other species, and called by him a subuniversal veil. Vittadini (in Fung. Mang., 147, pl. 18, fig. 2, 1835) describes and figures it in connection with his study of the development of his *Agaricus exquisitus*. But in this species he seems to confuse this delicate universal veil (protoblem) with what he terms the volva in several species of *Agaricus*. He also applies the term volva to the lower limb of the annulus in *Agaricus exquisitus* and in *Agaricus edulis*. He says (*l. c.*, 148) this delicate universal veil in *A. exquisitus* is perfectly similar to that which constitutes the veil of the "Tignose," *i. c.*, the scaly Amanitas like *A. muscaria*, etc. Vittadini also states (*l. c.* 147) that Trattinnick observed this delicate universal veil (protoblem) on *Agaricus edulis* (the species which Trattinnick describes as *A. edulis* is different from *A. campestris edulis* Vitt. or *A. rodmani* Pk.), but it appears that Vittadini misinterpreted Trattinnick's statment. The latter says, in order to prevent confusion one should avoid (*l. c.*, p. 73) taking for the edible one a mushroom (74), which may have also only the slightest trace of a membrane which in youth envelopes the entire mushroom, including pileus and stem, down to the roots. "Um Verwechslungen zu vermeiden, hüte man sich statt der Gugemuke einen Schwamm zu nehmen" (73), "(*d*) der auch nur die geringste Spur von einer Wulsthaut haben sollte, die in der Jugend den ganzen Schwamm mit sammt den Strunk und Hut bis auf die Wurzel verhüllet" (74 Die essbare Schwamme, 1830).

longitudinal section two such areas are seen, symmetrically situated on either side of the long axis and some distance from the surface of the fruit body. The annular zone is of quite limited extent as the

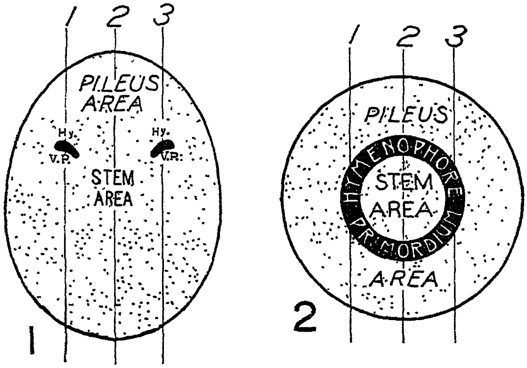

DIAGRAM 1 Lateral view through young basidiocarp representing early stage of differentiation into the primordia of the four principal parts; pileus area, stem area, hymenophore fundament (*Hy*) and veil primordium (*V. P.*).

DIAGRAM 2. Zenith view in young basidiocarp at same stage of fundaments, and annular hymenophore primordium. See text for details.

small area presented by its transection in Fig. 3 shows. The outline of this area in transection is somewhat elongated and rises at an oblique angle from the stem area, well shown in Fig. 3 and indicated in diagram 1. The area of the primordial hymenophore seen in the tangential section is much more extensive as shown in Fig. 4. The difference in the extent of these areas shown in median (Fig. 3) and tangential (Fig. 4) sections is clearly appreciated by reference to diagram 2.

Structure of the Young Hymenophore Primordium.—This internal annular zone of new growth arises by the origin of numerous. slender hyphal branches, rich in protoplasm, which are directed downward, or obliquely downward and outward. They have a more direct course than the hyphae of the basidiocarp primordium, the latter irregularly sinuous and interwoven, while the hyphae of the young hymenophore primordium are nearly or quite straight. Because of their small diameter and their slender, gradually tapering ends, they easily crowd their way through the rather open weft of hyphæ forming the ground tissue or fundamental plectenchyma. Fig. 9 is a highly magnified view of the hymenophore primordium

shown in the section represented in Fig. 3, from the right-hand area. The dark area in Fig. 9 represents the mass of deeply stained hyphæ of the new growth zone. Because of the compactness of the tissue, very little detail is shown. But along the middle portion of the figure between the lighter, open mesh of the ground tissue below and to the right, and the dark area of the hymenophore primordium above and to the left, a number of hyphæ in advance of the others are shown extending into the loose mesh of the ground tissue. These are nearly parallel and their extremities are more or less distant, because they are in advance of the greater number of new branches present in the more deeply staining area. No annular gill cavity is present at this time.

Growth and Increase of the Hymenophore Primordium.—The growth and further organization of the hymenophore primordium is readily studied by the aid of similar serial sections of successively older stages of the basidiocarps. Sections of such stages are repre-

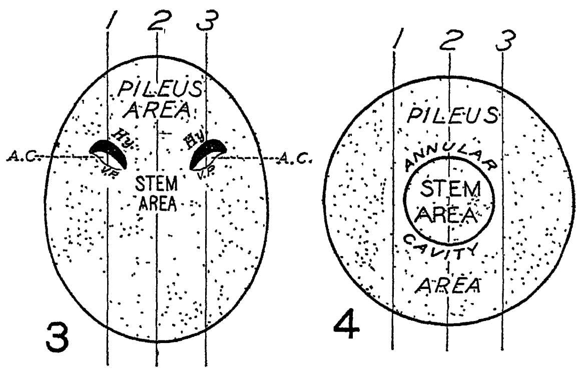

DIAGRAM 3. Lateral view through young basidiocarp at a slightly later stage of development than in diagram 1. *Hy* = hymenophore; *A. C.* = annular cavity; *V. P.* = veil primordium.

DIAGRAM 4. Zenith view in young basidiocarp at same stage of development. See text for details.

sented in Figs. 5–8 and 10–16. Diagrams 3 and 4 indicate how the sections were made. From the condition show in Figs. 3, 4 and 9, there is a rapid increase in the number of hyphæ in the zone of new growth, extending in the same direction, *i. e.,* downward and obliquely outward. During the increase in number the hyphæ become more crowded, are straighter and lie more nearly parallel. The

upper outer portion of this new zone of growth, *i. e.*, the hymenophore primordium, represents the early stage of the organization of the pileus margin: in other words, the annular internal zone of new growth is to be interpreted as the young primordium of hymenophore and pileus margin, the latter including the area from which the new hyphal branches arise as well as the basal area of these branches. Not only is there interstitial growth in the increase of these hyphal branches, the new ones crowding in between the older ones forming a more compact zone, but there is also a centrifugal increase in the periphery of the annular zone. The centrifugal growth of the pileus margin and hymenophore primordium is very characteristic.

The position and direction of the hyphæ of the young hymenophore primordium, as well as the increasing density of this area, is well shown in Figs. 10–16. The stem axis of all the figures is parallel with the long axis of the Plate. Several of these figures are highly magnified views of the hymenophore primordium shown in Figs. 5–7; Figs. 10 and 15 being highly magnified views of the hymenophore of Figs. 5 and 6, while Figs. 12 and 16 are highly magnified views of that in Figs. 7 and 8. Figs. 10 to 14 are from median longitudinal sections of the basidiocarps. Fig. 10 is from the right-hand side of the stem axis, *i. e.*, the stem axis is at the left. Figs. 11–14 are from the left-hand side of the stem axis, the stem axis therefore being on the right-hand of the figures. The increasing density of the elements of the young hymenophore is progressively shown in Figs. 10 to 13. With the increasing density the ends of the hyphæ reach more and more to the same level and thus tend to form an even surface which forms the transition to the palisade layer.

Origin of the General Annular Gill Cavity.—A striking feature in all these radial transections of the hymenophore zone and pileus margin is the curved outline of the zone as seen in transection. This is remarkably strong in Figs. 11 and 12 because the young hymenophore primordium extends for a considerable distance down around the apex of the stem fundament. This arched form of the young annular hymenophore zone is the result of epinastic growth of the pileus margin, which is very marked even in this very early stage in the organization. The rapid increase in the number of

the hyphæ in the young hymenophore, crowding in between the older ones, as well as their increase in diameter, produces a great pressure in this region. As a result of this increasing pressure within the arch a strong tension is exerted on the ground tissue below and adjacent to the arch. The ground tissue at this point is thus torn apart, forming a distinct opening, or cavity, beneath the young hymenophore, which is known as the annular gill cavity. The continuity as a general, annular, internal cavity can easily be determined by serial longitudinal sections through the young fruit body, the sections being made as indicated in diagrams 3 and 4, the knife travelling through the basidiocarp in the direction indicated by the lines 1, 2, 3. As the knife passes the region marked by the line 1, the sections will show a single cavity elongated transversely as shown in Figs. 6 and 8, 15 and 16. As the knife passes into the stem area the sections will show two cavities situated symmetrically as in Figs. 5 and 7 (or as in diagrams 3 and 4). Then as the knife passes out of the stem area, into the region indicated by the line 3, the sections will again show a single cavity elongated transversely.

The annular gill cavity[12] varies in strength in different individuals and at different stages of development. Sometimes it is very weak, at other times it is quite strong. The tearing apart of the ground tissue often leaves it with quite an open mesh, and the surface next the gill cavity is more or less frazzled. The gill cavity is stronger next the stem where the hymenophore is older, and is weaker toward the margin. Where the cavity is weak, isolated threads or irregular strands of the ground tissue are not completely torn away from the hymenophore, and the cavity is thus often traversed by lagging elements of the ground tissue. At a later stage, after the origin of the lamellæ, the annular cavity in some indi-

[12] In a recent paper, after describing the gills in *Coprinus micaceus*, Levine ("The Origin and Development of the Lamellæ in *Coprinus micaceus*," *Am. Jour. Bot.*, 1, 343–356, pls. 39, 40, 1914), makes the statement (p. 352) that "There is no general gill cavity as described by Hoffmann, deBary, Atkinson, and others." Since deBary ("Morphologie und Physiologie der Pilze, Flechten und Myxomyceten," 69, 1866) is the only person hitherto who has announced the presence of a general annular gill cavity in *Coprinus micaceus*, this statement by Levine can only be interpreted as a general denial of the presence of a general annular gill cavity in the species in which it has thus far been described, a rather rash statement which will be referred to again in the discussion of the origin of the lamellæ.

viduals may become nearly or quite closed by the increase in the elements of this ground tissue, which forms a portion of the marginal veil, but chiefly by the epinastic growth of the pileus margin which crowds this ground tissue up against the margin of the lamellæ, as shown in Figs. 32–38.

Organization of the Palisade Layer.—The level palisade layer of the hymenophore follows the primordial stage, immediately after the latter stage has become dense and compact by the increase in number and thickness of the parallel hyphal elements. The growing compactness of the primordial hymenophore zone is accompanied by the evening up of the hyphal ends into a plane surface. As the ends of the hyphæ broaden the free surface of the hymenophore becomes compact and smooth, or even. This is the level palisade stage of the hymenophore. It is a gradual, not abrupt, transition from the primordial stage. It begins next the stem, or in many cases on the outer surface of the upper part of the stem fundament as shown in Fig. 12. Here the palisade area, in radial section, rises upward at a strong oblique angle from the axis of the stem, and then grades into the primordial area toward the left. The palisade area progresses, like the primordial area and the pileus margin, in a centrifugal direction, the older portion lying next to, or on the upper part of the stem fundament.

The level palisade layer of the hymenophore, preceding the origin of the lamellæ, was first described by Hoffmann[13] in 1856, 1860, and 1861, in about a dozen species (see the later paragraph on the origin of the lamellæ for a list of species). DeBary[14] (1859, p. 386, 394) described the palisade layer of the young hymenophore in *Nyctalis asterophora* and *parasitica,* as having radial folds from its

[13] Hoffmann, H., "Die Pollinarien und Spermatien von Agaricus," *Bot. Zeit.,* 14: 137–148; 153–163, pl. 5, 1856 Beiträge zur Entwickelungsgeschichte und Anatomie der Agaricinen," *Bot. Zeit.,* 18: 389–395; 397–404, pls. 13, 14, 1860. Icones Analyticae Fungorum; Abbildungen und Beschreibungen von Pilzen mit besonderer Rucksicht auf Anatomie und Entwickelungsgeschichte," 1–105, pls. 1–24, 1861.

[14] DeBary, A., "Zur Kenntnis einer Agaricinen," *Bot. Zeit.,* 17: 385–388; 393–398; 401–404, pl. 13, 1859.

[15] DeBary; A., "Morphologie und Physiologie der Pilze, Flechten und Myxomyceten," Leipzig, 1866. "Vergleichende Morphologie und Biologie der Pilze, Mycetozoen und Bacterien," 1884. "Comparative Morphology and Biology of the Fungi, Mycetozoa and Bacteria," Oxford, 1887.

earliest appearance. But as this interpretation was shown by Hoffman (1860, p. 402) to be wrong, deBary[15] (1866, p. 63; 1884, p. 58, 312; 1887, p. 55, 289) studied a number of other forms and agreed with Hoffman that the earliest stage of the young palisade hymenophore was level, or smooth.

III. The Differentiation of Parts in the Primordial Ground Tissue.

There are four principal parts of the fruit body which are differentiated in the ground tissue of the basidiocarp primordium, the *hymenophore, pileus, stem* and *veil.* The primary differentiation in the ground tissue of *Agaricus rodmani* is the origin of the hymenophore primordium. As described above this arises as an internal annular zone of new growth, a little above the middle of the small oval primordial basidiocarp. It consists of numerous hyphal branches which extend downward and obliquely outward. These new hyphæ are nearly or quite parallel, are at first slender and taper very gradually to the free end. This form assists them in making their way through the mesh of the ground tissue. They are rich in protoplasm, become compacted by increase in number and diameter, and thus in sections, take on a deep color when stains are applied (see Figs. 3–16). The origin of this internal hymenophore zone differentiates at once the stem and pileus areas, or fundaments, but the organization of the stem and pileus occurs later.

In the early origin of the primordial hymenophore zone, *Agaricus rodmani* agrees with *Agaricus campestris*[16] as presented in a study of the commercial varieties, *alaska* and *bohemia.* In that paper I pointed out that we should not necessarily expect the first evidence of differentiation to be the appearance of the hymenophore primordium in plants not yet studied though it is probable that at least some of the other species of *Agaricus* (*Psalliota*) may show the same peculiarity. This suggestion is justified by the situation in *Agaricus rodmani.* The same situation exists in *Armillaria mellea.*[17]

16 Atkinson, Geo. F., "The Development of *Agaricus compestris,*" *Bot.*
Universal Veil' in *Agaricus,*" *Myc. Centralb.*, 2, 13–19 pls. 1–3, 1914.
Gaz., 42: 241–264, pls. 7–12, 1906.

17 Atkinson, Geo. F., "The Development of *Armillaria mellea,*" *Myc. Centralb.*, 4: 113–121, pls. 1, 2, 1914.

In the specimens of *Agaricus arvensis*[18] studied, the lagging behind of the ground tissue below the zone where the hymenophore primordium arises occurs before any differentiation of this zone is distinguishable, for a light area with a looser mesh occurs in an annular zone which marks the distinction between the stem and pileus areas. Or the lagging behind of the ground tissue may occur simultaneously with the appearance of the primordial hymenophore zone and the outline of the pileus area. In a number of forms studied by Fayod[19] the primordium of the pileus is organized, in the apex of the young homogeneous basidiocarp, as a new zone of growth, in the form of an inverted bowl, shown by the darker staining of the hyphæ rich in protoplasm, forming a pileus producing layer ("couche piléogène"). This method of differentiation he accepts as a general law for the Agariceæ, the only exception admitted by him being the coriaceous forms of *Lentinus*. *Agaricus rodmani*, the commercial varieties of *Agaricus campestris* (*columbia* and *alaska*) and *Stropharia ambigua* (Peck) Zeller,[20] also form exceptions to this rule. The primordium of the pileus in these forms may be regarded as diffuse within the upper part of the young basidiocarp, the differentiation and organization of the pileus margin beginning in conjunction with the organization of the primordial hymenophore zone, though in *Stropharia ambigua* the inverted bowl-shaped zone of new growth in the upper part of the pileus area is soon organized.[20] Other forms recently investigated which conform to the general law laid down by Fayod, are certain species of *Hypholoma* (Allen),[21] *Hypholoma fascicularis* and *Clitocybe laccata* by Beer,[22] *Lepiota*[23] *clypeolaria* and *Amanitopsis vaginata*.[24]

[18] Atkinson, Geo. F., "The Development of *Agaricus arvensis* and *A. comtulus*," *Am. Jour. Bot*, 1, 3–22, pls. 1, 2, 1914. "Homology of the 'Universal Veil' in *Agaricus*," *Myc. Centralbl.*, 2, 13–19 pls. 1–3, 1914.

[19] Fayod, V., "Prodrome d'une histoire naturelle des Agaricinées," *Ann. Sci. Nat. Bot.*, VII., 9, 181–411, pls. 6, 7, 1889.

[20] Zeller, S. M., "The Development of *Stropharia ambigua*," *Mycologia*, 6, 139–145: pls. 124, 125, 1914.

[21] Allen, Caroline L., "The Development of some Species of *Hypholoma*," *Ann. Myc.*, 4, 387–394, pls. 5–7, 1906.

[22] Beer, R., "Notes on the Development of the Carpophore in Some Agarincaceæ," *Ann. Bot.*, 25^2: 683–689, pl. 52, 1911.

[23] Atkinson, Geo. F., "The Development of *Lepiota clypeolaria*," *Ann. Myc.*, 12, 346–356, pls. 13–16, 1914.

Organization of the Pileus.—The organization of the pileus begins in connection with the primordial hymenophore zone. The upper part of this zone is very probably to be regarded as the primordium of the pileus margin which then increases by centrifugal growth. It is marked from an early period by strong epinastic growth, so the margin becomes strikingly involute, a feature also characteristic of *Agaricus campestris,*[25]. *A. arvensis,*[26] *A. comtulus,* etc., as I have earlier described. The general relation of the hyphæ in the primordium of the pileus margin is a parallel one, and they become more and more strongly incurved as a result of epinasty. As the pileus primordium increases in width by marginal growth, it also increases in thickness, more perceptibly so farther back from the margin where the new growth is older. In this way the organization of the pileus advances more and more into the outer zone of the ground tissue, the blematogen, and becomes consolidated with it.[27]

Organization of the Stem.—The stem area is delimited at the same time as the pileus area by the origin of the young hymenophore zone, but its organization and differentiation from the ground tissue seems to lag behind the early stages of the organization of the pileus margin. While a general and more or less diffuse growth and expansion occurs for some time in the stem area, the first evidence of a differentiation from the ground tissue is seen in the organization of the stem surface. The outline of the stem may be compared to that of a broad, flat cone, since the stem at first is very short and

[24] Atkinson, Geo. F., "The Development of *Amanitopsis vaginata,*" *Ann. Myc*, 12, 369–392, pls. 17–19, 1914.

[25] Atkinson, Geo. F., "The Development of *Agaricus campestris,*" *Bot. Gaz.*, 42: 241–264, pls. 7–12, 1906 (see figures 11 and 12).

[26] Atkinson, Geo. F., "The Development of *Agaricus arvensis* and *A. comtulus.*" *Am. Jour. Bot.*, 1: 3–22, pls. 1, 2, 1914.

[27] In *Agaricus campestris* var. *edulis,* Vittadini ("Fun. Mang.," 44, pl. 6, fig. 1, 1835) in a young oval fruit body, figures and describes the outline of the pileus within a stout volva, and states that, during the course of development, the volva is ruptured circularly, and the margin of the pileus as it emerges is held for a time against the stem by the lower limb of the annulus. His account of the release of the volva (blematogen) from the pileus does not seem clear, and his figures do not show the transition stage from *a* to *b* in figure 1 of his Plate VI In *Agaricus rodmani* nor in any other species of *Agaricus* (*Psalliota*) have I ever seen any indication of the clear cut outline of the pileus surface as distinct from the blematogen, such as Vittadini shows at *a,* fig. 1.

broad, and the surface slopes outward at a strong angle. The surface outline of the stem is quite clearly differentiated from the loose ground tissue forming the marginal veil, because of the deeper staining property of the stem shown in longitudinal sections (Fig. 32). Its differentiation and organization agrees entirely with that described for *Agaricus campestris*,[28] *Agaricus arvensis* and *A. comtulus*.[29]

Organization of the Marginal Veil.—The organization and limits of the marginal veil, or partial veil, as it is sometimes called, in *Agaricus arvensis, A. comtulus* and *A. campestris*, has been very fully discussed in previous papers[29] (13–15, 1914), briefly in another[30] (17, 1914). Its organization and composition in *Agaricus rodmani* is in the main similar, its different features being due to its more robust character, the stouter pileus and shorter stem. The fundament of the marginal veil is ground tissue in the angle between the primordial hymenophore zone and the stem fundament, including on its outer surface a narrow section of the blematogen layer. The ground tissue in this angle is indicated in *VP* (veil primordium) in diagram 3, and the corresponding areas in Figs. 3, 5, 7, 9–14 can readily be understood. There is considerable increase in this ground tissue by growth of the portion clothing the stem fundament. It is also added to by growth of the hyphæ at the margin of the pileus. The mass of the loose inner surface is often crowded up against the edges of the gills by the involute margin of the pileus pushing it upward, due to epinastic growth.

In such robust specimens usually presented by *Agaricus rodmani* the blematogen layer is comparatively thick but still forms a comparatively small portion of the marginal veil, and lies on the outer under surface of the lower limb of the annulus. By the incurving of the thick margin of the pileus its edge is crowded into the thick veil, and presses against the stem, thus separating the veil, which later becomes the annulus, into an upper and lower limb. As stated above, the fact that the short stem elongates but little in comparison

[28] Atkinson, Geo. F., "The Development of *Agaricus campestris*," *Bot. Gaz.*, 42: 241–264, pls. 7–12, 1906.

[29] Atkinson, Geo. F., "The Development of *Agaricus arvensis* and *A. comtulus*," *Am. Jour. Bot.*, 1. 3–22 pls. 1, 2, 1914.

[30] Atkinson, Geo. F., "Homology of the Universal Veil in *Agaricus*, *Myc. Cantralb.*, 5, 13–19, pls. 1–13, 1914.

with that of *Agaricus campestris, arvensis,* and a number of other species, the veil is usually not ripped up from the lower part of the stem as it is in the other species. A thin layer on the stem below the annulus is often cracked into distinct areas or patches, the margins of the areas sometimes being partially exfoliated. The partial exfoliation of the under part of the lower limb of the annulus frequently occurs, and then the lower limb itself has a double edge as described above, and as shown in several of the figures of Plate I. In *Agaricus campestris, arvensis, augustus, subrufescens, placomyces,* and others, the freeing of the lower part of the annulus from the stem is very extensive, since as the stem elongates the veil is ripped off for a considerable distance. In *Agaricus rodmani,* as the pileus expands, the lower limb of the veil clings to the stem, splitting off from the outer surface of the pileus margin as the latter is withdrawn. The inner or upper limb of the veil remains attached to the edge of the pileus margin for a longer time, but is eventually separated.

IV. Origin and Development of the Lamellæ.

Origin of the Gill Salients.—The development of the hymenophore is progressive and centrifugal. As described in the previous section, the primordial hymenophore zone originates in conjunction with the primordium of the pileus margin and lies in the angle separating the stem and pileus areas. The organization of the level palisade zone of the hymenophore from the primordial stage, begins in the older region, *i. e.,* next the stem. The margin of the pileus, primordial hymenophore and palisade zone all progress by growth in a centrifugal direction, the younger, later stages succeeding the earlier. The lamellæ succeed the level palisade zone and arise as downward growing salients of the same. These salients begin next the stem (or in some cases on it). They are regularly spaced and progress in a radial, centrifugal direction. The origin of the salients from the level palisade stage is well shown in Figs. 17–21.

In Figs. 18 and 20, different stages in the origin of the salients are shown. Three gill salients are seen in Fig. 20. At the left side of Fig. 20 is the level palisade. Next it to the right is a very low salient. Continuing to read toward the right, the second and third salients are successively stronger. While the hyphal struc-

ture is not very distinctly shown in in this figure, due to the difficulty of illumination which will produce on the photographic plate the same degree of resolution which can be detected by the eye, still the palisade character is evident. A similar situation is seen in Fig. 18, but the progression in the origin and growth of the salients is to be read from right to left. A somewhat later stage is shown in Fig. 19. Here the hyphal structure is well shown. The palisade character of the exposed surface of the hymenophore is very clearly shown. This figure gives us some suggestion of the factors operating in the formation of the gill salients. The elements of the palisade layer increase by interstitial growth, *i. e.*, by new branches which crowd in between the older ones. At the same time the elongate cells composing the palisade layer increase in diameter. In the primordial stage they passed from the terete tapering condition to the cylindrical form. Now they pass from the cylindrical to the clavate form, as well as increasing somewhat in diameter throughout. This produces a great pressure on the level palisade zone, which if continued, must result in throwing the level palisade layer into folds.

Another factor now comes into play which prevents the palisade layer from being thrown into a series of irregular folds. This is the downward growth, by elongation, of the subadjacent tramal hyphæ, along regularly spaced radial areas, beginning next the stem and proceeding in a centrifugal direction toward the margin of the pileus. These radial areas of subadjacent tramal hyphæ, elongating downwards, push the palisade area downward into corresponding radial salients. These salients are the first evidence of folds or ridges which appear in the young hymenophore. They are the gill salients, and by continued growth form the lamellæ themselves.

Fig. 19 presents another very interesting situation. This is the flaring, or fantailing, of the gill salients very soon after their emergence below the level of the general palisade surface. This is very clearly one of the first results of the release from the pressure to which the elongate cells were subject in the level palisade condition. Another still more interesting feature at this stage is the pressure to which the neutral portion of the level palisade is subjected as a result of this fantailing of the gill origins. The flanks of the young

gill salients thus crowd against the intervening neutral palisade cells, more strongly against their free ends. This presses these intervening, neutral, radiating areas of the original level palisade into the form of ridges which thus alternate with the radiating gill salients. These intervening ridges between the young gill salients are very conspicuous in a corresponding stage of gill development in *Coprinus micaceus* as I have shown in another paper. This situation is a comparatively old stage in the development of the lamellæ and is one of the peculiar features presented by a number of the Agaricaceæ, which led Levine[31] to mistake these intervening ridges between comparatively old gill salients for the first ridges to appear in the hymenophore primordium of *Coprinus micaceus*. These ridges he thought were the first evidence of the gills. The gills were described as arising from the splitting of these first ridges and the union of approximate halves of adjacent ridges to form the gills between them. This matter will be referred to below when another peculiar situation is described which also assisted in leading this author astray.

Relation of the Different Phases of Hymenophore Development in the Young Basidiocarp.—Figs. 17–23 represent different phases of the organization and development of the hymenophore in a single basidiocarp, during an intermediate stage of its development. The relation of these different phases is determined by a study of longitudinal serial sections passing from near the stem to the margin of the pileus. With the exception of Fig. 20, Figs. 17–23 are all from the same plant, selected to represent the relation of different phases of the young hymenophore. The sections from which the photographs were taken were parallel with the axis of the stem, and thus were nearly or quite perpendicular to the hymenophore, or under surface of the pileus. The general plane of the hymenophore, or under surface of the pileus, is slightly arched, but for all practical purposes of this study, the plane is perpendicular to the stem axis, so that the sections are perpendicular to the general hymenophore surface, or plane. Fig. 17 is from a section near the stem, corresponding to line 4 in diagram 6 (diagram 6 is intended to illustrate the situation presented by the figures in Plate 5, but serves to illus-

[31] Levine, M., "The Origin and Development of the Lamellæ in *Coprinus micaceus*," *Am. Jour. Bot.*, 1, 343–356, pls. 39, 40, 1914.

trate also the relations now under consideration). An examination of the relation of line 4, in diagram 6, to the gill salients, the palisade and primordial areas, will assist in making the relation of the phases of the hymenophore presented in Fig. 17 very clear.

In the middle of the figure, or section, the gill salients are cut transversely. On either side of the middle they are cut obliquely, the more so the nearer the palisade area the salients are cut. But when the gill is so young, the structure of an oblique section at this angle is practically the same as in a transection. Since the hymenophore is older next the stem, and progressively younger toward the margin of the pileus, the gill salients are older next the stem, and younger next the palisade area, where they are very low and grade off insensibly into the level palisade zone. Toward the left and right from the middle of such a section as is represented by Fig. 17, the salients become less and less prominent until they grade insensibly into the level palisade zone on either side. In like manner the palisade zone grades to the left and right into the primordial zone, and this into the margin of the pileus, showing practically the same relation, so far as the palisade and primordial zones are concerned, as in a radial section.

Fig. 21 is from a section made near the outer ends of the middle salients, about in the region represented by line 7 in diagram 6. Only a few salients are shown, these are very low, and on either side soon grade insensibly into the palisade zone. Fig. 22 is from a section made in the region indicated by line 8 in diagram 6. Here there are no gill salients (nor any evidence of ridges in the hymenophore), a broad area in the middle is the palisade area, and this grades on either side insensibly into the primoridal area. Fig. 23 is from a section made in the region indicated by line 9 in diagram 6. It is entirely within the primordial zone, near the margin of the pileus. Knowing this relation of the different phases of the hymenophore, one can observe the transition of the primordial phase into the level palisade phase, and this into the phase of the salients. In other words, one can study the method of origin of the lamellæ by a study of the different phases of the gill salients in the area of transition from the palisade zone into the zone of the young gills.

Relation of the Hymenophore to the Stem.—One of the taxonomic characters employed for the genus *Agaricus* (*Psalliota*) is the free condition of the gills from the stem. In *Agaricus campestris,* while the gills are usually free, they are close to the stem, and in some cases are even adnexed to the stem. The same is true of *Agaricus rodmani.* Peck[32] says of the lamellæ,—" free, reaching nearly or quite to the stem. It is possible that in some examples the gills may be broadly attached to the stem fundament at the time of their origin, but become free at maturity by changes in the relation and tensions of the parts during expansion of the plant. That the young lamellæ are sometimes broadly attached around the upper end of the stem fundament has been observed in a number of examples during this study of development. In some examples the attachment of the stem is very broad, in others slight, and in still others the lamellæ are free from the time of their origin.

Deceptive Appearance of Sections near the Stem when the Young Lamellæ are Attached.—In studying the origin of the lamellæ in plants where the hymenophore, from its earliest appearance, is entirely free from the stem, little difficulty is experienced in the interpretation of the situation presented, in case there is a fairly well formed annular cavity prior to the origin of the gill salients. Longitudinal sections next the stem then present the simple situation shown in Fig. 17. But in those cases where the hymenophore primordium extends downward on the outer surface of the stem apex, as shown in Figs. 11 and 12, sections passing from the stem through this portion of the hymenophore, after the origin of the gill salients, present a complicated structure, which may be very confusing unless all the features of the situation are taken into consideration. As stated above the stem axis of the sections from which Figs. 11 and 12 were made is parallel with the longitudinal direction of the plate. In very young basidiocarps, as already described, the stem surface slopes outward at a very strong angle as shown in Fig. 32.

Now, when the gill salients begin to form by downward, or outward, extension of the level palisade, in those cases where the hymenophore primordium extends down on the surface of the stem,

[32] Peck, C. H., N. Y. State Mus. Nat. Hist Rept., 36, 45, 1885.

the salients first appear over this portion of the hymenophore, because it is the older. The older portion of the salients, therefore, extend outward perpendicular to the stem surface. Since their progression is centrifugal, the salients gradually extend over the angle between stem and pileus where their growth is downward. Since the growth in width of the salients is perpendicular to the surface of the level hymenophore at any point, there are formed, in the cases

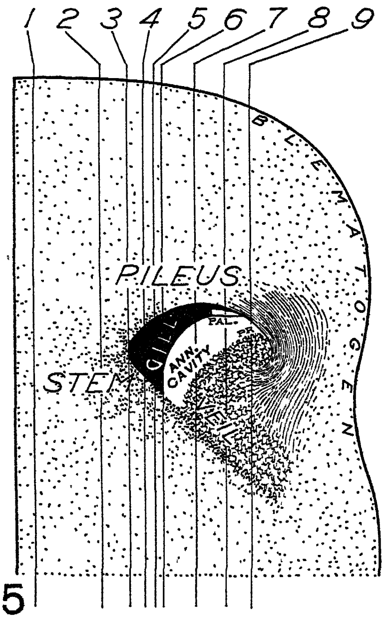

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Diagram 5. Lateral view through one half of a basidiocarp in an intermediate stage of development, showing (1) the strongly sloping surface of the stem; (2) the partly organized pileus margin which is becoming in volute because of eipnastic growth; (3) the hymenophore presenting three stages of development, (*a*) the oldest portion, the gill area extending on the under side of the pileus and far down on the surface of the stem (adnate at this stage), (*b*) the palisade area (*PAL*) distal to the gill area on under side of pileus, and (*c*) the primordial area (*PR*) near margin of pileus; (4) annular cavity; (5) the loose ground tissue of the marginal veil; and (6) the blematogen layer. See text.

under consideration, a series of little stalls, or pigeon holes, around the stem apex, between the young gills in the angle between the stem

and pileus. This situation is illustrated in Figs. 24–31, from selected serial sections of the same basidiocarp. The sections were parallel with the long axis of the stem. Diagrams 5 and 6 illustrate the situation in this basidiocarp and show exactly how the scetions were made.

Fig. 24 is from a nearly median longitudinal section, made in the region indicated by line 1 of diagrams 5 and 6, which presents a situation practically the same as a median section. The outline of the narrow young gill salient is well shown in Fig. 24, with the distinct annular cavity. The gill salients are strongly curved and in the form of crescents, the lower limb of the crescent extending far down on the outwardly sloping stem surface; the upper limb reaching out on the under surface of the pileus, where it grades into the level palisade zone, and the latter into the primordial zone. The relation of parts is clearly represented by diagram 5. It is quite easy to form a mental picture of the series of little stalls, or pigeon holes, around the upper part of the stem between these crescentic salients.

Fig. 25 is from a section in the region indicated by line 2 of diagrams 5 and 6. The line 2 in diagram 6 shows how the section passes through the side of the stem and obliquely across a few of the young gills, then on either side passing through the level palisade and primordial zones. These features are clearly seen in Fig. 25. Fig. 26 is from the region indicated by line 3: Fig. 27 that of line 4; Fig. 28 that of line 5; Fig. 29 that of line 6; and Fig. 30 that of line 7, of diagrams 5 and 6 (figures of sections in the region indicated by lines 8 and 9 are not shown from this basidiocarp, but there is nothing essentially different in them from figures 22 and 23 from another plant). Fig. 31 is a more highly magnified view of the middle portion of Fig. 27.

Figs. 26–29 and 31 present a very interesting situation. They show transections of the stalls, or pigeon holes, mentioned above. Unless caution is observed this situation would be very misleading. The gill salients are attached above to the under side of the pileus and below to the surface of the stem, and this attachment above and below existed from the time of the origin of the salients. However, the attachment below is not that of the margin of the gills, but of their origin from the stem, since the salients grew outward from the

level palisade organized in this region over the upper surface of the stem.

Similar sections of *Coprinus micaceus*[33] through the region of the attached gills was one of the features contributing to the incorrect interpretation, by Levine, of the origin of the lamellæ in this plant, as shown by his Figs. 13 and 14. The palisade cells on the sides and in the upper angle of these pigeon holes could easily give the impression that the gills had their origin from isolated radial areas of new growth of palisade cells, these areas, or "ridges" of

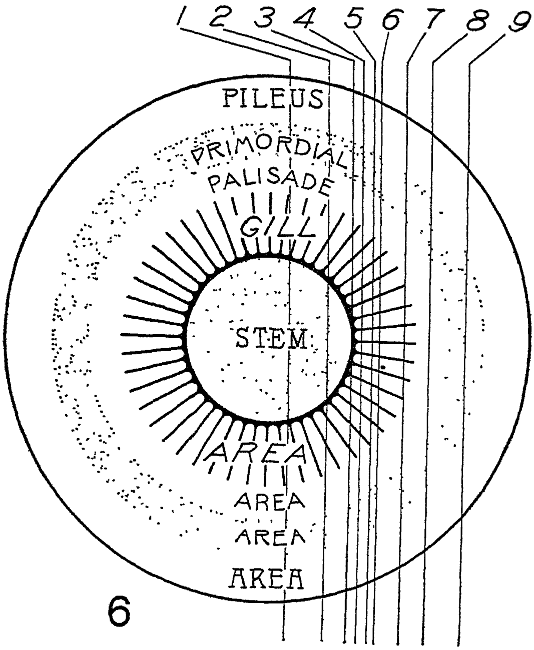

DIAGRAM 6. Zenith view in a basidiocarp of the same age as that represented in diagram 5. See text for details not marked in the diagram.

palisade cells parting as they increase, forming a lining over the ground tissue or partitions of these little stalls, and thus enclosing "the notch between the gills."

Relation of the Gills to the Involute Margin of the Pileus.—There are other peculiar situations presented in the development of

[33] Levine, M., "The Origin and Development of *Coprinus micaceus*," *Am. Jour. Bot.*, 1, 343–356, pls. 124, 125, 1914.

Agaricus rodmani (and other species) which may lead to serious misinterpretation unless great caution is observed. This is the relation of the gills to the involute margin of the pileus and to the marginal veil, shown in a series of longitudinal, "tangential" sections of basidiocarps at an age when the gill salients, by centrifugal progression, have nearly or quite reached the margin of the pileus. The various features of this situation are presented in Figs. 32–42. The figures are photographs of selected serial sections from a single basidiocarp. Diagrams 7 and 8 illustrate the situation in this basidiocarp and the lines show the regions in which the sections were made.

In Fig. 32, from a nearly median longitudinal section (in the region of line 1), the involute margin of the pileus is shown. An indefinite portion of the outer, lighter stained area is the blematogen. The margin of the pileus is so strongly involute that the edge is curved upward toward the gills and has crowded the mass of the ground tissue constituting the inner portion of the veil up against the middle zone of the lamellæ. The attachment of this ground tissue to the margin of the gills is not very firm, though there is some adherence of the hyphæ. The attachment has occurred after the ground tissue was crowded against the margins of the gills by the strongly upturned, involute pileus margin. The strongly involute margin of the pileus is well shown also in several of the figures in Plate VII. The position of the upturned edge of the involute pileus margin is such that the loose ground tissue of the inner portion of the veil is lifted up against the middle area of the lamellæ, while the edges of the gills near the stem and also near the margin of the pileus are free. This is very clearly shown in Fig. 33, from a section in the region of line 2 in diagrams 7 and 8.

Figs. 34 and 35 are from sections in the region of lines 3 and 4 just passing through the surface of the stem in the angle at the junction of the pileus and stem. The hymenophore extends a short distance down on the upper surface of the stem, but the gills are only "adnexed," not extending so far down on the stem fundament as in the basidiocarp represented on Plate XII. and in diagrams 5 and 6. In the middle area of Fig. 35, the nearly solid block of tissue in the same level with the gills on either side, is hymenophore tissue from

the surface of the stem, and a portion of the same area in Fig. 34 also belongs to the hymenophore. The hymenophore, as interpreted here, and in all of my recent papers, includes not only all parts of the lamellæ and the palisade cells between adjacent lamellæ, but also a thin, often indefinite zone of the subadjacent tissue corresponding to the subhymenial tissue of the palisade between the gill origins. As figure 35 shows, the "stalls," or "pigeon holes," in the angle of pileus and stem are quite small because the gill origins extend but

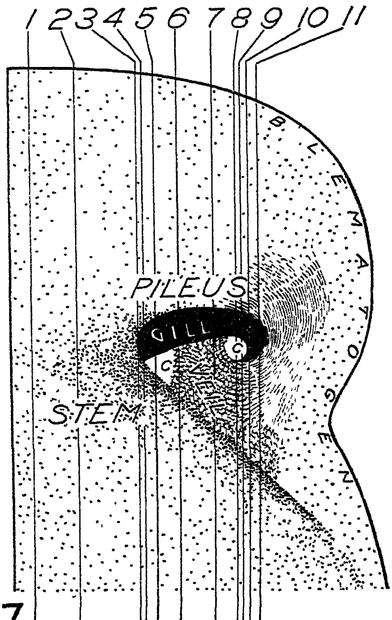

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Diagram 7. Lateral view through one half of a basidiocarp in an older stage than that represented in diagrams 5 and 6. The hymenophore has all passed over into the gill stage. The gill area does not extend so far down on the stem as in diagram 5. The margin of the pileus is more strongly involute and the veil tissue has been crowded up against the middle portion of the gills. C = the portion of the annular cavity not filled. See text for other details not marked here.

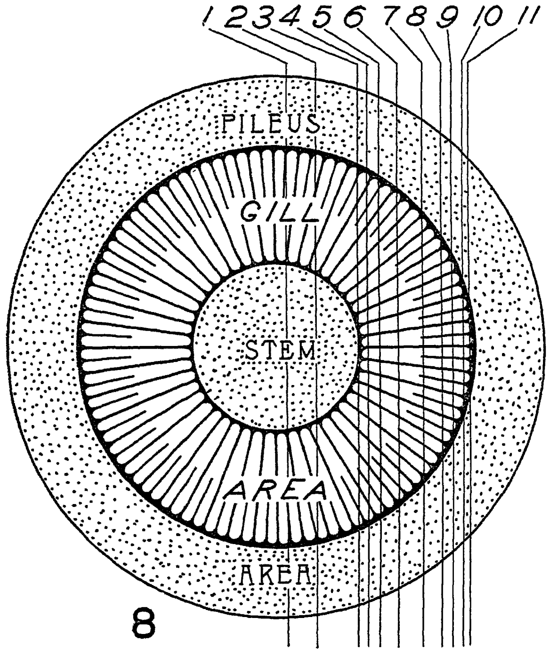
a short distance down on the upper surface of the stem. The abrupt ending of this hymenophore tissue below is even with the margins of the gills on either side, and the lower edge is free from the ground

tissue clothing the stem fundament, as shown by the clear line between the two. This indicates that the portion of the hymenophore on the upper surface of the stem projected by growth slightly above the level of the stem surface, or above that of the ground tissue. In Fig. 34 the distinct boundary line of the more compact tissue shows, but it is in contact with the ground issue below since this section did not pass outside of the junction of stem and pileus fundaments. In Fig. 35 a few of the gills on either side of the middle are free from the ground tissue below. Outside of this on either side (the middle zone between stem and pileus margin) a number of the gills are attached to the ground tissue pressed up against them by the involute pileus margin. On either side of these areas, *i. e.*, near the margin of the pileus, the gills are free.

Fig. 36 is from a section in the region indicated by line 5 in diagram 7. The middle of the section, according to line 5, would pass through the space of the annular cavity near the stem which has not been filled by the upward crowding of the ground tissue. The margin of the gills here should therefore be free from the ground tissue below. This is shown to be the case in Fig. 36, for the gills over the middle portion of the figure (which are near the stem). On either side of this area, however, the section passes through the zone where the ground tissue is crowded up against the gills, while toward the margin of the pileus the gills are again free from the ground tissue.

Figs. 37 and 38 are from sections in the region of lines 6 and 7 respectively, of diagram 7. Both sections are thus "tangents" through the region where the ground tissue in contact with the middle zone of the gills would be continuous and of considerable extent, but the area in the region of line 6 would be of greater extent than that in the region of line 7. This corresponds with the situation shown in Figs. 37 and 38, while toward the margin of the pileus on either side the gills are free. Figs. 39 and 40 are from the region of lines 8 and 9. These pass through the portion of the annular cavity between the margin of the pileus and the ground tissue crowded up against the middle region of the hymenophore. The gills therefore would not be in contact with the ground tissue below. In Figs. 39 and 40, however, it is clear that on either side the gills

are attached below as well as above. The attachment below is not the margin of these gills, but their point of origin from the inner surface of the involute pileus margin. This will be clearly understood from a study of Figs. 41 and 42.



. DIAGRAM 8. Zenith view into a basidiocarp of the same age. See text for details not marked.

Figs. 41 and 42 are from sections in the region of lines 10 and 11 in diagrams 7 and 8. The gills are attached above and below. But it is very clear here that the attachment below, as well as above, is to the pileus. Since the gills are downward growths of the level palisade, formed on the under surface of the pileus (*i. e.*, perpendicular to the level palisade), the attachment below in these figures, as well as that above, is at the point of origin of the gills, and must not be interpeted as an attachment of the gill margin to the stem.

The First Ridges, or Salients, of the Hymenophore are the Fundaments of the Lamellæ Themselves.—The question of the origin

of the lamellæ is of renewed interest since it has recently been stated that one of the problems yet to be worked out in the Agaricaceæ is the origin of the lamellæ.[34] The evidence presented in support of this sweeping, and rather surprising statement, is made, so far as we can judge, on the basis of an investigation of *Coprinus micaceus*. It carries with it the implied charge that all of the observations and statements in regard to the origin of the gills, covering a period of more than half a century, are incorrect. In the case of my own work on *Agaricus campestris*,[35] *Armillaria mellea*,[36] *Lepiota clypeolaria*,[37] *Agaricus arvensis*[38] and *A. comtulus* it can be most positively reaffirmed that the lamellæ originate as described, as downward, radial growths of the level palisade portion of the hymenophore. The evidence was so clear in these examples that at the time of the study it did not seem desirable to present full series of "tangential" sections of the different stages in the origin of the gills, particularly as the method of origin agreed in all respects with that described in more than a dozen different species in earlier works. The present study of *Agaricus rodmani* was undertaken, not only for the purpose of examining into the significance of the double annulus, but also for the purpose of examining the different stages in the organization of the hymenophore primordium, the level palisade stage, and the origin of the gills, in a species closely related to *Agaricus campestris*. It is very clear that the present study has fully confirmed the earlier statements with reference to the origin of the lamellæ. Material has also been grown, and the young stages obtained for sectioning in the following commercial forms of *Agaricus: A. campestris* varieties *bohemia* and *alaska*, and *A.* "*villaticus*."

[34] Levine, M., "The Origin and Development of the Lamellæ in *Coprinus micaceus*," *Am. Jour. Bot.*, 1, 343–356, pls. 39, 40, 1914.

[35] Atkinson, Geo. F., The Development of *Agaricus compestris*," *Bot. Gaz.*, 42, 241–264, pls. 7–12, 1906.

[36] Atkinson, Geo. F., "The Development of *Armillaria mellea*," *Myc. Centralb.*, 4, 113–121, pls. 1, 2, 1914.

[37] Atkinson, Geo. F., "The Development of *Lepiota clypeolaria*," *Ann. Myc.*, 12, 346–356, pls. 13–16, 1914.

[38] Atkinson, Geo. F., "The Development of *Agaricus arvensis* and *A. comtulus*," *Am. Jour. Bot.*, 1, 3–22, pls. 1, 2, 1914. "Homology of the Universal Veil in *Agaricus*," *Myc. Centralb.*, 5, 13–19, pls. 1–3, 1914.

The situation in certain species of *Coprinus,* where the margins of the gills are attached to the stem before maturity, and break away during the expansion of the plants, has for a long time interested me, and I have intended to investigate certain of the species for the purpose of comparing the situation in this genus with that described in *Amanita rubescens*[39] by deBary, *A. muscaria*[40] by Brefeld and in *Amanitopsis vaginata*[41] by myself, where there is no general prelamellar cavity, and the first evidence of the lamellæ is the differentiation of a series of radial trabeculæ in the hymenophore primordium, continuous with the stem and trama of the pileus. This investigation was delayed, however, until the autumn of 1914. Material of three species, *Coprinus comatus, atramentarius* and *micaceus,* was studied, and the results will be published in another paper. This much may he said here, that these three species do not belong to the *Amanita* type but to the *Agaricus* type. There is a strong, annular, prelamellar cavity in *Coprinus comatus,* a weak one in *C. atramentarius* and *micaceus,* but in all three the lamellæ originate as downward-growing salients of a level palisade zone, exactly as described here for *Agaricus rodmani,* the only difference being in those specific features relating to the structure of the lamellæ. Levine based his interpretation of the origin of the lamellæ in *Coprinus micaceus* on complicated and rather well advanced stages of their development. Had the origin of these complicated structures been sought it is probable that the origin of the lamellæ would have been found.

Of the plants thus far studied the following species may be mentioned as examples of the *Agaricus* type in which the origin of the lamellæ has been clearly and correctly described, those by Hoffmann more than half a century ago. *Agaricus carneotomentosus* (*Panus torulosus*) by Hoffmann[42] (1856, p. 145); *Cantharellus*

[39] De Bary, A., "Morphologie und Physiologie der Pilze, Flechten und Myxomyceten," Leipzig, 1866. "Vergleichende Morphologie and Biologie der Pilze, Mycetozoen und Bacterien," 1884. "Comparative Morphology and Biology of the Fungi, Mycetozoa and Bacteria," Oxford, 1887.

[40] Brefeld, O., "Botanische Untersuchungen über Schimmelpilze," 3, Basidiomyceten, I., I.–IV., 1–226; pls. 6–11, 1887.

[41] Atkinson, Geo. F., "The Development of *Amanitopsis vaginata,*" *Ann. Myc.,* 12, 369–392, pls. 17–19, 1914.

[42] Hoffmann, H., "Die Pollinarien und Spermatien von Agaricus," *Bot. Zeit.,* 14· 137–148; 153–163, pls. 5, 1856.

tubaeformis, C. aurantiacus, Panus stipticus, Pleurotus tremulus, Omphalia umbellifera, O. pyxidata, Marasmius epiphyllus by Hoffmann[43] (1860); *Collybia velutipes, C. fusipes, Hygrophorus chlorophanus, Galera mycenopsis, Hebeloma mesophaeus, Coprinus fimitarius, Paxillus involutus, Entoloma sericeum,* and others by Hoffmann[44] (1861); *Mycena vulgaris, Collybia dryophila, Nyctalis parasitica, Clitocybe cyathiformis,* and *Cantharellus infundibuliformis* by deBary[45] (1866, 1884, 1887) the latter two in conjunction with Woronin; *Coprinus lagopus* by Brefeld[46] (1877, p. 127); *Agaricus campestris* by Atkinson[47] (1906); *Hypholoma* by Miss Allen[48] (1906) and by Beer[49] (1911); *Stropharia ambigua*[50] by Zeller (1914); *Agaricus arvensis* and *comtulus,*[51] and *Armillaria mellea*[52] by Atkinson (1914).

SUMMARY.

1. The lower limb of the double annulus of *Agaricus rodmani* is not a true volva like that of the Amanitas thus far studied. It is composed of a short segment of the blematogen plus some of the inner tissue of the marginal veil. The greater portion of the blematogen remains "concrete" with or consolidated with the surface of

43 "Beiträge zur Entwickelungsgeschichte und Anatomie der Agaricinen," *Bot. Zeit.*, 18: 389–395; 397–404, pls. 13, 14, 1860.

44 Hoffmann, H., "Icones Analyticæ Fungorum; Abbildungen und Bescreibungen von Pilzen mit besonderer Rucksicht auf Anatomie und Entwickelungsgeschichte, 1–105, pls. 1–24, 1861.

45 DeBary, A., "Morphologie und Physiologie der Pilze, Flechten und Mycetozoen," Leipzig, 1866. "Vergleichende Morphologie und Biologie der Pilze, Mycetozoen und Bacterien," 1884. "Comparative Morphology and Biology of the Fungi, Mycetezoa and Bacteria," Oxford, 1887.

46 Brefeld, O., Botanische Untersuchungen über Schimmelpilze," 3, Basidiomyceten, I., I.–IV., 1–226; pls. 6–11, 1887.

47 Atkinson, Geo. F., "The Development of *Agaricus campestris*," *Bot.* Gaz., 42: 241–264, pls. 7–12, 1906.

48 Allen, Caroline L., "The Development of Some Species of *Hypholoma*," *Ann. Myc.*, 4: 387–394, pls. 5–7, 1906.

49 Beer, R., "Notes on the Development of the Carpophore in Some Agaricaceæ," *Ann. Bot.*, 25[2]: 683–689, pl. 52, 1911.

50 Zeller, S. M., "The Development of *Stropharia ambigua*," *Mycologia*, 6: 139–145, pls. 124, 125, 1914.

51 Atkinson, Geo. F., "The Development of *Agaricus arvensis* and *A. comtulus*," *Am. Jour. Bot.*, 1: 3–22, pls. 1, 2, 1914.

52 Atkinson, Geo. F., "The Development of *Armillaria mellea*," *Myc. Centralb.*, 4: 113–121, pls. 1, 2, 1914.

the pileus, while in *Amanita* the blematogen is finally delimited from the surface of the pileus by a cleavage layer. A double annulus homologous with that of *Agaricus rodmani* is often present in certain other species of *Agaricus*.

2. The primordium of the basidiocarp is oval in form, and homogeneous in structure, consisting of intricately interwoven hyphæ.

3. The four primary parts of the basidiocarp, pileus, stem, marginal veil and hymenophore, are first differentiated by the origin of the hymenophore fundament.

4. The hymenophore primordium arises as an internal, annular zone of new growth toward the upper part of the young basidiocarp. It consists of slender hyphæ rich in protoplasm, parallel, and directed obliquely downward. The lower outer surface is at first more or less open and uneven, presenting a frayed or fimbriate appearance. By continued growth and multiplication of these hyphæ the hymenophore primordium becomes more compact and the under surface becomes even, forming a level palisade zone. Growth of the hymenophore proceeds in a centrifugal direction, the older portions being next the stem fundament. By the epinastic growth of the pileus margin the hymenophore takes on the form of an annular arch.

5. The increase in number and diameter of the elements of the hymenophore fundament produce a tension upon the ground tissue beneath, which lags behind in growth and is torn away from the under surface of the hymenophore, thus forming an annular, prelamellar cavity. This cavity may later be nearly filled by the ground tissue of the inner portion of the veil which increases in bulk, and is often crowded up against the young gills by the involute margin of the pileus.

6. The lamellæ originate as downward growing radial salients of the level palisade zone, beginning next, or on the stem, according as the hymenophore primordium is free from or extends down on the upper portion of the stem fundament. They progress in a centrifugal direction. In an intermediate stage of development or the basidiocarp, all three stages of the hymenophore may be present, the zone of gill salients next the stem, then the level palisade zone, and beyond this the primordial zone.

7. The first ridges, or salients, which appear in connection with the hymenophore are the fundaments of the lamellæ themselves, and the palisade layer is continuous over their edges as well as in the notch between adjacent salients.

DESCRIPTION OF PLATES VII.–XIII.

PLATE VII.

Mature and nearly mature plants of *Agaricus rodmani* showing the double nature of the annulus with its edge grooved; forming an upper and lower limb; the short stem, involute margin of the pileus, etc. $\times 2/3$ diameter. For details see text.

PLATE VIII.

Mature and very robust plants from parking between sidewalk and street. Real size. See text.

PLATES IX.–XIII.

The magnifications of the photomicrographs are as follows: Figs. 3–8; $\times$ 9 diameters. Fig. 33; $\times$ 10 diameters. Figs. 1, 2; $\times$ 12 diameters. Fig. 32; $\times$ 13 diameters. Figs. 34–36; $\times$ 20 diameters. Fig. 17; $\times$ 23 diameters. Figs. 15, 16; $\times$ 28 diameters. Figs. 21–30, 37–42; $\times$ 30 diameters Fig. 31; $\times$ 100 diameters. Fig. 12; $\times$ 110 diameters. Fig. 13; $\times$ 155 diameters. Figs. 10, 11; $\times$ 160 diameters Fig. 18; $\times$ 170 diameters. Figs 9–14; $\times$ 225 diameters. Figs. 19, 20; $\times$ 250 diameters.

PLATE IX.

FIG. 1. (No. 18.) Young stage of basidiocarp primordium.

FIG. 2. (No. 20.) Somewhat older stage of basidiocarp primordium, but still in the undifferentiated stage.

FIG. 3. (No. $^{27}/_{1}$) Earliest stage of differentiation in the young basidiocarp, median longitunial section showing a transection of the internal annular hymenophore fundament, the general prelamellar cavity not yet formed. Pileus fundament is above, stem fundament below, and veil fundament underneath the hymenophore primordium (see Fig. 9).

FIG. 4. (No. $^{27}/_{4}$.) Longitudinal section of the same basidiocarp, "tangential" to the hymenophore primordium, which is shown as a transverse deeply staining area.

FIG. 5. (No. $^{23}/_{1}$.) Median longitudinal section through a basidiocarp just after the formation of the general, annular, prelamellar cavity. The hymenophore is still in the primordial condition (see Fig. 10) but does not extend down on the surface of the upper part of the stem fundament.

FIG. 6. (No. $^{23}/_{3}$.) Longitudinal section of the same basidiocarp, "tangential" to the hymenophore and annular cavity (see Fig. 13).

FIG. 7. (No. $^{12}/_{2}$.) Median longitudinal section of a basidiocarp just after the formation of the general, annular, prelamellar cavity. The

hymenophore is still entirely in the primordial stage (see Fig 11) and extends for a considerable distance down on the surface of the upper part of the stem fundament.

FIG. 8. (No. $^{12}/_{7}$.) Longitudinal section of the same basidiocarp, "tangential" to the hymenophore and annular cavity (see Fig. 16).

PLATE X.

FIG. 9. (No. $^{27}/_{7}$.) More highly magnified view of the transection of the hymenophore primordium shown in Fig. 3; stem axis at the left. In the darker area (hymenophore primordium) the hyphae extend downward and obliquely outward toward, and some projecting into, the veil fundament below, which consists of a loose mesh of interwoven hyphae.

FIG. 10. (No. $^{23}/_{1}$.) More highly magnified view of the transection of the hymenophore primordium and annular cavity shown in Fig. 5 (axis of stem at the left).

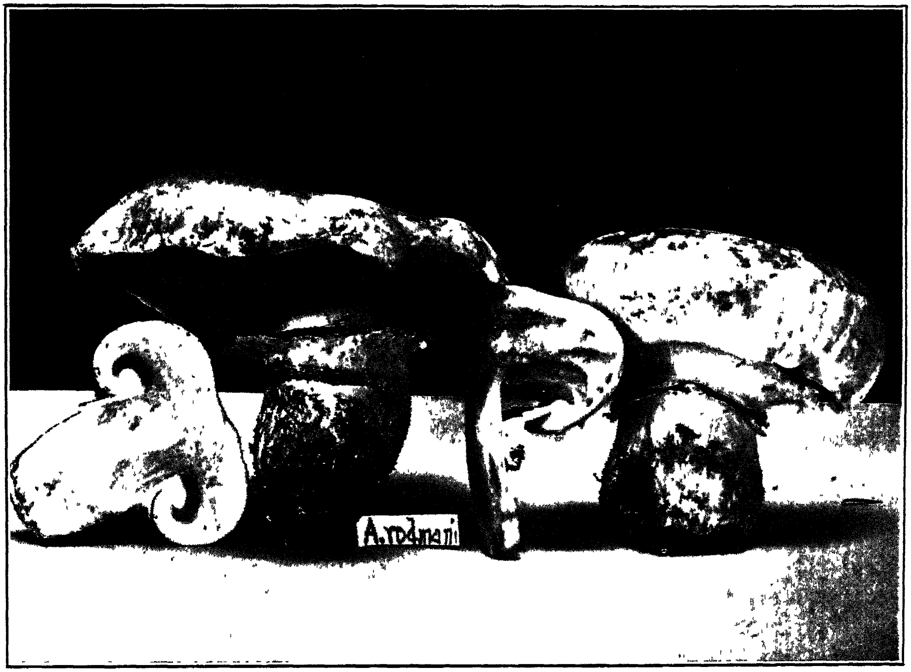
FIG. 11. (No. $^{12}/_{2}$.) More highly magnified view of the transection of the hymenophore primordium and annular cavity shown in Fig. 7 (stem axis at right). The hymenophore primordium extends down over the upper part of the stem outer surface. Veil fundament in the angle below, the ground tissue tearing apart and separting from the fimbriate under surface of the hymenophore

FIG. 12. (No. $^{3}/_{3}$.) Transection of hymenophore and annular cavity, showing same view as Fig. 11 (stem axis at right) but in another basidiocarp and slightly older stage; the portion of the hymenophore primordium on the upper part of the stem fundament has become transformed into the level palisade stage.

FIGS. 13 and 14. (No. $^{2}/_{2}$.) Section of another basidiocarp showing the hymenophore and annular cavity in same stage as in Fig. 10, at different magnifications (stem axis at right). Hymenophore primordium with fimbriate edge. Ground tissue below (veil fundament) breaking away from the fimbriate surface of the hymenophore as a result of the tension produced by the rapid increase in number and size of the elements of the hymenophore and the lagging behind of the ground tissue below, thus forming the annular cavity. These sections are radial and parallel with the direction of the later lamellæ. The elements of the hymenophore here are somewhat clustered, the slender ends of the hyphæ clinging in groups as the lower surface of the hymenophore is loosened by the tension of the increase above.

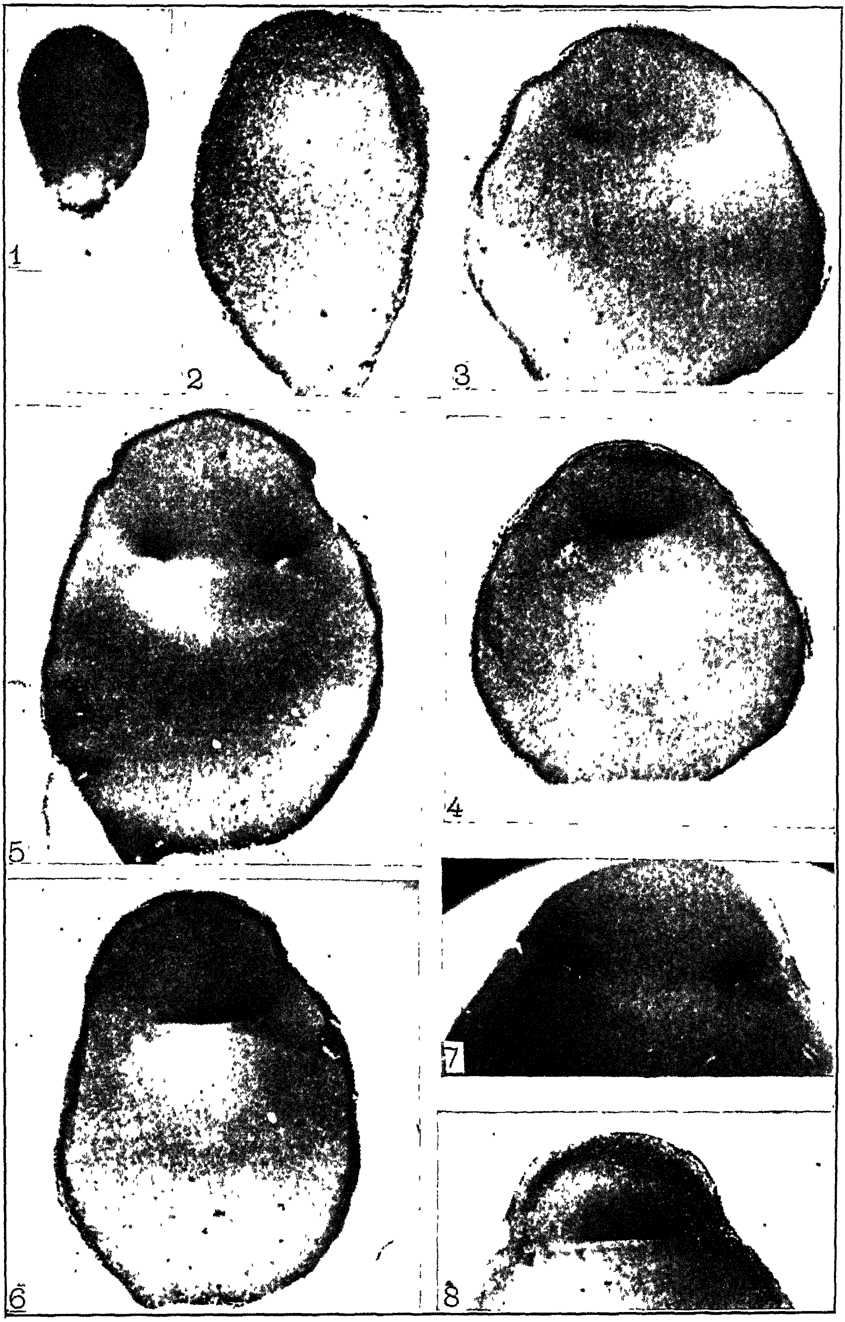
FIG. 15. (No. $^{23}/_{3}$.) "Tangential" section of the hymenophore primordium, more highly magnified view of the hymenophore and general, annular, prelamellar cavity shown in Fig. 6. Note the fimbriate lower surface of the hymenophore primordium, and the loose ground tissue (primordium of veil) below separating from it and formıng the annular cavity. The structure of the hymenophore primordium is homogeneous, there is not the slightest evidence of gill salients, or of ridges of any sort, which precede or have any relation to the lamellæ which are to arise later.

FIG. 16. (No. $^{12}/_{7}$.) "Tangential" section of hymenophore primordium, annular cavity and veil fundament, a more highly magnified view of this part of the basidiocarp shown in Fig. 8. Details as in Fig. 15.

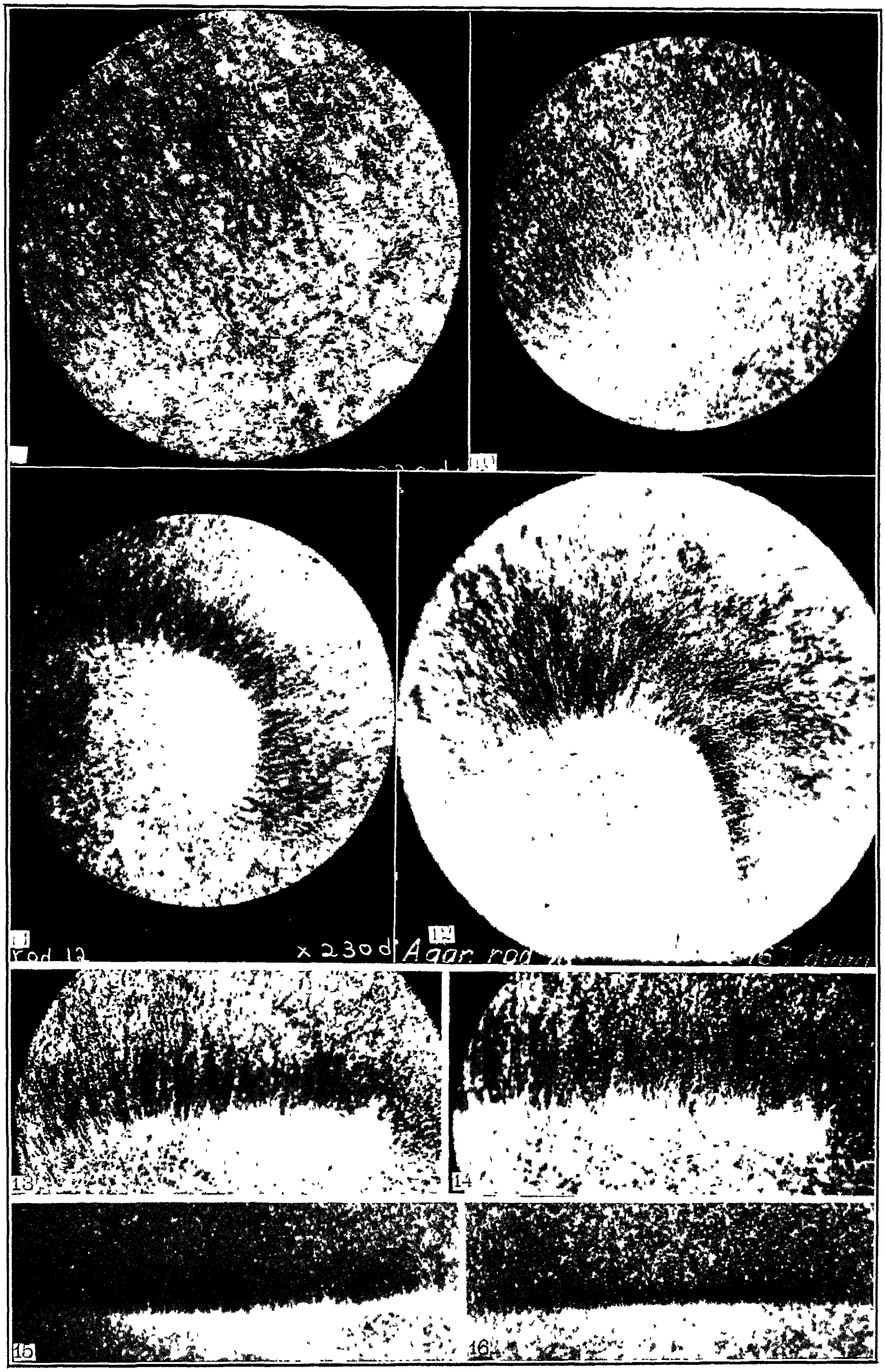


AGARICUS RODMANI

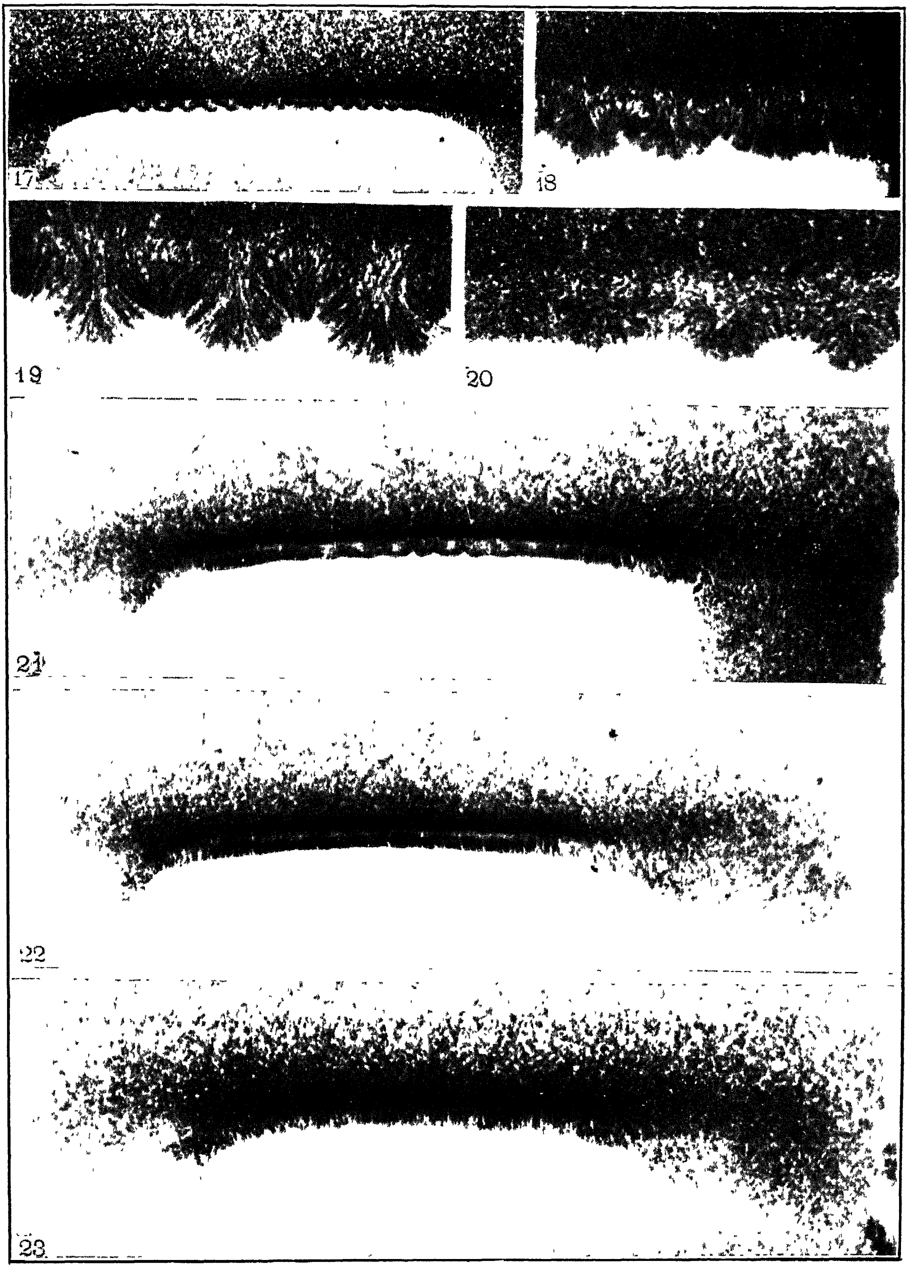
AGARICUS RODMANI



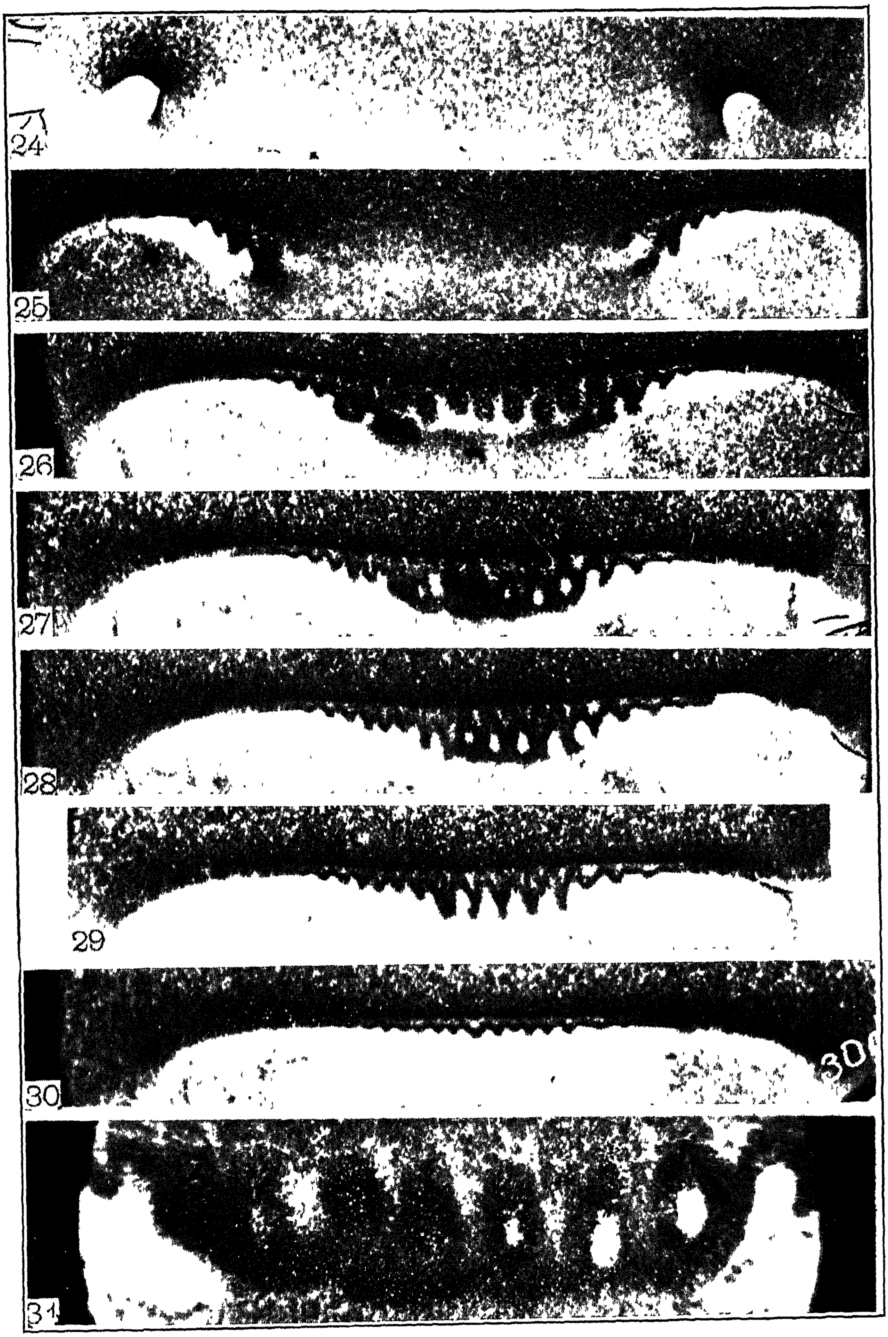
AGARICUS RODMANI



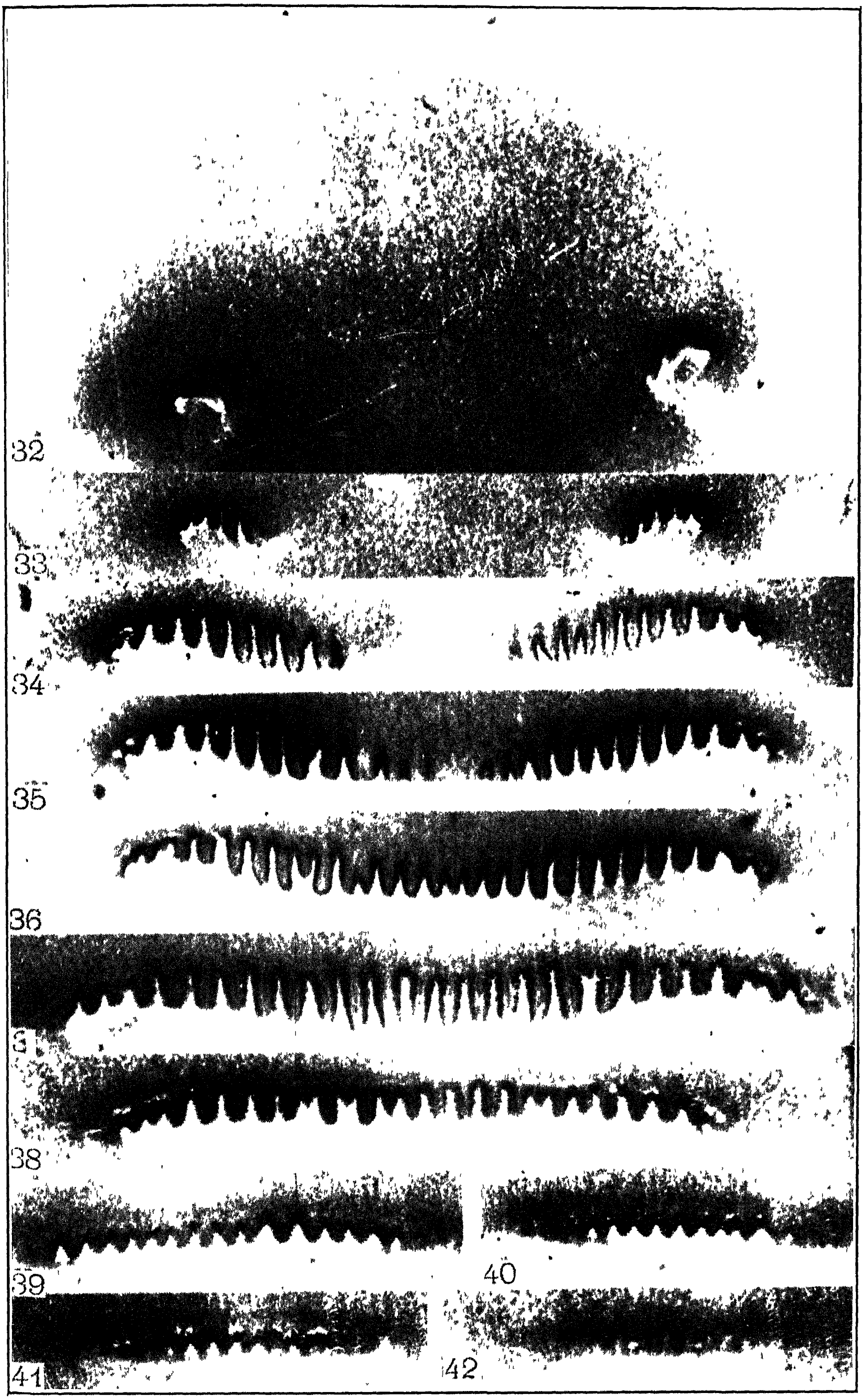
AGARICUS RODMANI



AGARICUS RODMANI



AGARICUS RODMANI



AGARICUS RODMANI

PLATE XI.

FIGS. 17–19 and 21–23, all from a single basidiocarp (No. 5/2), from selected serial sections parallel with the axis of the stem and "tangential" in the pileus. Fig. 17 is from near the stem, and shows the three stages of the developing hymenophore, primordial zone, level palisade zone, and the zone of gill salients (transected) with different stages in the origin of the latter from the level palisade condition (see text for details). The general annular cavity is well shown.

FIG. 18. More highly magnified view of portion of the same section in the region of the origin of the gill salients from the level palisade stage.

FIG. 19. More highly magnified view of the young gill salients, showing how they flare, or fantail, when released from the pressure to which the elements are subjected in the level palisade zone, also showing how this flaring of the young gill salients crowds the intervening palisade cells of the original level into "ridges," these ridges of palisade in the notch between two lamellæ being formed later than the gill salients, and as a result of the lateral pressure of the flaring salients. For details see the text.

FIG. 20. (No. 1/2.) Section from another basidiocarp showing transition from the level palisade stage to the gill salients.

FIG. 21. Section nearer the margin of the pileus than that shown in Fig. 17. In the middle area the gill salients are cut near their distal end where they are very low (see text for details). Transition to level palisade and primordial zone on either side.

FIG. 22. Section still nearer the margin of the pileus showing the level palisade zone in the center, and the primordial zone on either side.

FIG. 23. Section still nearer the margin of the pileus, entirely through the primordial zone.

PLATE XII.

FIGS. 24–31. Selected serial sections from a single basidiocarp (No. 1/3), parallel with the stem axis and from nearly median in the stem to midway from stem surface to the margin of the pileus. Here the hymenophore extends for some distance down on the outward sloping surface of the stem fundament, and there are little "stalls" or pigeon holes between them in the angle at junction of pileus and stem. See text for details.

PLATE XIII.

FIGS. 32–42. Selected serial sections from a single basidiocarp (No. 11), parallel with the axis of the stem and from median in the stem to "tangential" in the margin of the pileus. See text for details.

THE EULER–LAPLACE THEOREM ON THE DECREASE OF THE ECCENTRICITY OF THE ORBITS OF THE HEAVENLY BODIES UNDER THE SECULAR ACTION OF A RESISTING MEDIUM.

By T. J. J. SEE.

(*Read April 24, 1915.*)

In the "Mécanique Céleste," Liv. VII., Chap. VI., §§ 29–30, and Liv. X., Chap. VII., § 18, Laplace has developed the mathematical theory of the secular action of a resisting medium, and applied it to the motions of the moon and planets. The first discussion herein cited was published in Volume III. of the "Mécanique Céleste," 1802. It is on this discussion by Laplace that modern investigators chiefly base their treatment of the problems of a resisting medium. Laplace's development of the theory therefore has been of great service to science for more than a century.

Recently, while occupied with a careful review of the theories of magnetism and of gravitation since the time of Newton, I had occasion to examine Euler's "Dissertatio de Magnete," 1744, "Opuscula," 1746–51; and while looking into this work was surprised to find that Euler had preceded Laplace in his development of the chief effects of a resisting medium by more than half a century. Euler's work on the resisting medium will be found in the volume of "Opuscula," Berlin, 1746, in the paper "De Relaxatione Motus Planetarum," pp. 245–276.

Having shown that the aphelia are undisturbed by resistance, Euler considers in section XVII. the equations for the mean motion, and the return to perihelion, after changes in the mean motion by the increments representing a whole revolution:

$$nt + 2\pi, \quad nt + 4\pi, \quad nt + 6\pi, \quad nt + 8\pi, \text{ etc.}$$

Euler puts for the planetary orbit about the sun,

$h = a(1 - e) =$ perihelion distance,

$g = a(1 - e^2) = p =$ latus rectum of the orbit,

$y = r =$ radius vector of the planet,

$Z = e =$ the eccentricity of the orbit,

$t =$ true anomaly $= v$, in the notation now commonly used,

$s =$ arc of the orbit, reckoned from perihelion,

$c =$ sun's mean distance,

$= \mu\alpha$, where α is the earth's equatorial semi-diameter, and

μ a number which expresses the sun's mean distance in this unit. Euler uses a solar parallax of 13″, and takes $c = 15866\alpha$. With the values now adopted in astronomy we have about $c = 23445\alpha$. In some of his numerical work Euler uses $c = g = a(1 - e^2)$, which is admissible when we neglect the square of the eccentricity.

Euler also uses a small angle of deviation due to the angular effects of resistance, $z = \theta$, such that $\tan z = 2g/3c$; and then takes the equation for the Keplerian ellipse

$$r = \frac{a(1 - e^2)}{1 + e\cos v},$$

to have the form of an ellipse modified by resistance

$$\frac{1}{r} = \frac{1}{p}(1 + e\cos v) = \frac{1}{p} + \frac{e\cos v}{p} + P,$$

where P is function of the time, but modified by a very small quantity depending on the effects of the secular action of the resisting medium.

From the equations of the disturbed ellipse, in his notation,

$$\frac{1}{y} = \frac{1}{g} + \frac{\zeta}{g}\cos t + P,$$

$$P = \frac{1}{c}\left(t - \sin t - \tfrac{1}{2}\zeta\sin t + \tfrac{1}{2}\zeta t\cos t + \tfrac{3}{4}\zeta\zeta t - \tfrac{2}{3}\zeta\zeta\sin t - \tfrac{1}{24}\zeta\zeta\sin 2t\right),$$

Euler develops the following table:

If	there will be
$t = 0,$	$P = 0,$
$t = \pi - \theta,$	$P = \frac{1}{c}\left(\pi - \frac{1}{2}\zeta\pi - \frac{4g}{\zeta c}\right),$
$t = 2\pi,$	$P = \frac{1}{c}(2\pi + \zeta\pi),$
$t = 3\pi - \theta,$	$P = \frac{1}{c}\left(3\pi - \frac{3}{2}\zeta\pi - \frac{4g}{\zeta c}\right),$
$t = 4\pi,$	$P = \frac{1}{c}(4\pi + 2\zeta\pi),$
$t = 5\pi - \theta,$	$P = \frac{1}{c}\left(5\pi - \frac{5}{2}\zeta\pi - \frac{4g}{\zeta c}\right).$

He remarks that when therefore for perihelion we have

$$\frac{1}{y} = \frac{1 + \zeta}{g} + P,$$

and for aphelion

$$\frac{1}{y} = \frac{1 - \zeta}{g} + P,$$

if $t = 0,$	$\frac{1}{y} = \frac{1 + \zeta}{g} + 0,$
$t = \pi - \theta,$	$\frac{1}{y} = \frac{1 - \zeta}{g} + \frac{\pi}{c}(1 - \frac{1}{2}\zeta),$
$t = 2\pi,$	$\frac{1}{y} = \frac{1 + \zeta}{g} + \frac{2\pi}{c}(1 + \frac{1}{2}\zeta),$
$t = 3\pi - \theta,$	$\frac{1}{y} = \frac{1 - \zeta}{g} + \frac{3\pi}{c}(1 - \frac{1}{2}\zeta),$
$t = 4\pi,$	$\frac{1}{y} = \frac{1 + \zeta}{g} + \frac{4\pi}{c}(1 + \frac{1}{2}\zeta),$
$t = 5\pi - \theta,$	$\frac{1}{y} = \frac{1 - \zeta}{g} + \frac{5\pi}{c}(1 - \frac{1}{2}\zeta);$

it being understood that the final angle $4g/3c$ is neglected as very small.

Euler next considers the effect of i whole revolutions:

$$t = 2i\pi,$$

$$\frac{1}{y} = \frac{1+\zeta}{g} + \frac{2i\pi}{c}(1+\tfrac{1}{2}\zeta);$$

and finds for the radius vector:

$$y = \frac{g}{1+\zeta} - \frac{2i\pi}{c}\frac{(1+\frac{1}{2}\zeta)gg}{(1+\zeta)^2}.$$

Putting for the following aphelion, $t = (2i+1)\pi - \theta$, there will result

$$\frac{1}{y} = \frac{1-\zeta}{g} + \frac{(2i+1)\pi}{c}(1-\tfrac{1}{2}\zeta);$$

whence the radius vector becomes

$$y = \frac{g}{1-\zeta} - \frac{(2i+1)\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2}.$$

The successive distances of the planet from the sun are diminished in the following manner:

I. Perihelion	$\frac{g}{1+\zeta} = 0,$
Aphelion	$\frac{g}{1-\zeta} - \frac{\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2},$
II. Perihelion	$\frac{g}{1+\zeta} - \frac{2\pi(1+\frac{1}{2}\zeta)gg}{c(1+\zeta)^2},$
Aphelion	$\frac{g}{1-\zeta} - \frac{3\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2},$
III. Perihelion	$\frac{g}{1+\zeta} - \frac{4\pi(1+\frac{1}{2}\zeta)gg}{c(1+\zeta)^2},$
Aphelion	$\frac{g}{1-\zeta} - \frac{5\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2}$, etc.

In any revolution about the sun the perihelion advances by the interval

$$\frac{2\pi(1+\frac{1}{2}\zeta)gg}{c(1+\zeta)^2};$$

and the aphelion regresses by the interval

$$\frac{2\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2};$$

the mean distance therefore decreases in the interval about $2\pi gg/c$; and after i revolutions this decrease in the mean distance will be $2i\pi gg/c$.

Accordingly, after i planetary revolutions, the perihelion distance from the sun becomes:

$$\frac{g}{1+\zeta}-\frac{2i\pi(1+\frac{1}{2}\zeta)gg}{c(1+\zeta)^2};$$

and the following aphelion distance:

$$\frac{g}{1-\zeta}-\frac{(2i+1)\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2}.$$

The addition of these values, after i revolutions, effects the transverse axis of the orbit:

$$\frac{2g}{1-\zeta\zeta}-\frac{4i\pi gg}{c(1-\zeta\zeta)^2}-\frac{\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2}.$$

Here indeed, since the time is to be defined, the time from perihelion to aphelion may be omitted; and thus after i revolutions the transverse axis of the orbit is found to be:

$$\frac{2g}{1-\zeta\zeta}-\frac{4i\pi gg}{c(1-\zeta\zeta)^2};$$

wherefore also the initial transverse axis is assumed equal to $2g/(1-\zeta\zeta)$.

If, therefore, the distance from the perihelion to the sun after i revolutions, which is equal to

$$\frac{g}{1+\zeta}-\frac{2i\pi(1+\frac{1}{2}\zeta)gg}{c(1+\zeta)^2},$$

be subtracted from the distance from the aphelion to the sun, which would develop in the same time, and found to be equal to

$$\frac{g}{1-\zeta} - \frac{2i\pi(1-\frac{1}{2}\zeta)gg}{c(1-\zeta)^2},$$

it will give for the distance of the foci after i revolutions

$$\frac{2\zeta g}{1-\zeta\zeta} - \frac{2i\pi\zeta gg(3-\zeta\zeta)}{c(1-\zeta\zeta)^2}.$$

The initial transverse axis was $2g/(1-\zeta\zeta)$, and if we divide this into the last expression, we get for the eccentricity of the orbit at this time: $\zeta - 3i\pi\zeta g/c$; terms in ζ^3 being neglected as insensible.

In Euler's paper the factor 3 in the last term is inadvertently omitted. He remarks that the original eccentricity was ζ, whereas after i revolutions it is decreased by the negative term shown above, and thus is subject to a secular diminution, owing to the secular action of the resisting medium.

After this discussion Euler reaches the conclusion: "A resistentia ergo excentricitas continuo minuitur, orbitaeque planetarum propius ad figuram circularem reducuntur" (p. 271).

He therefore recognized clearly that the effect of a resisting medium is to decrease the eccentricity incessantly, and to render the orbit more and more circular; and had reached this important conclusion some fifty-six years (1746) before the corresponding theorem was established by Laplace in 1802.

Accordingly as Euler's reasoning is essentially rigorous, though not the same as that of Laplace, it is evident that he was the first discoverer of the theorem which is of such fundamental importance in the theories of cosmogony.

It is remarkable that although Laplace had this theorem clearly before his mind for a quarter of a century at the close of his life (1802–1827) he did not once suspect that the planets and satellites had originated in the distance and through the action of a resisting medium had neared the centers about which they now revolve, and thus acquired the wonderful circularity of their orbits.

It is well known that Laplace continually refers to these bodies as detached by rotation, in the form of zones of vapor, as first

outlined in his nebular hypothesis of 1796. He thus misled the scientific world for more than a century, till the capture theory, involving formation in the distance with subsequent approach to their central masses, under the secular action of a resisting medium, was developed by the present writer in 1908–10.

It is equally well known that Laplace always held the comets to be foreign to our system—another misleading doctrine in cosmogony, finally overthrown in 1910 by the independent researches of Strömgren of Copenhagen, and the present writer, who showed that the comets are surviving residues of the ancient nebula which formed our solar system.

In my "Researches," Vol. II., pp. 138–139, I have drawn attention to two letters from Euler to the Royal Society, pointing out, as early as 1749, that the earth was once beyond the present orbit of Saturn. He does not there discuss the secular decrease of the eccentricity of the planetary orbits; yet as he had grounds for holding to a secular approach to the central masses, he was the first writer to outline sound views in cosmogony.

Under the circumstances it appears appropriate that the theorem on the secular decrease of the eccentricities of the orbits of bodies moving in resisting media, should be known by the name of the Euler-Laplace theorem. This recognizes the correct historical development, as now made out; and probably will always hold a fundamental place in the science of celestial evolution.

Mare Island, California,
April 6, 1915.

// PROCEEDINGS

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AMERICAN PHILOSOPHICAL SOCIETY

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SYMPOSIUM ON THE EARTH: ITS FIGURE, DIMENSIONS AND THE CONSTITUTION OF ITS INTERIOR.

(*Concluded from page 308.*)

IV.

VARIATIONS OF LATITUDE: THEIR BEARING UPON OUR KNOWLEDGE OF THE INTERIOR OF THE EARTH.

BY FRANK SCHLESINGER.

To review even hastily the contributions that astronomy has made to our knowledge of the figure and dimensions of the earth and the constitution of its interior, would consume more time than I can fairly claim as my share this afternoon. Let me therefore pass over those points that are on accepted ground and are matters of general agreement from the different points of view represented in this symposium; and let me dwell instead upon certain recent developments especially in need of consideration, concerning which the astronomer desires the criticism and help of the geologist, the seismologist, the physicist, and the meteorologist. These developments have come to us directly or indirectly through a study of latitude variations, so that most of what I shall have to say will deal with this subject.

Although variations of latitude are in a sense a very recent addi-

tion to our knowledge, yet on the theoretical side, at least, we find the beginning more than a century and a half ago. In 1755 Euler considered "the rotation of solid and rigid bodies" in a memoir that is now recognized as the foundation stone for our edifice. He showed that if such a body is projected into space it will exhibit two kinds of rotation; the first of these is the familiar one that corresponds to the day in the case of the earth; the other is more subtle and corresponds to the variation of latitude. By reason of this the axis of the diurnal rotation is continually changing within the body, progressing in a regular way and coming back after a time to its earlier positions. An ordinary top gives us a simple example of this kind of rotation. The spinner imparts to the top a motion of translation as well as a rotation, and if we wish to study the rotation we must arrest the translation in some way. This we can do by letting the top fall upon a hard surface in which the iron peg soon wears a minute hole for itself, and the effect is to stop the translation of the top without modifying seriously the rotation. Then we can see that while the top is turning very rapidly around an axis, this axis is itself rotating in a comparatively leisurely way. Just the same thing is occurring with the earth: the point (or pole) at which the axis of the daily rotation pierces the surface of the earth is continually in motion. If we could take to the neighborhood of the pole a modern instrument, and if we could observe there at leisure and in comfort, we should have no particular difficulty in finding the position of the pole within a meter. But if we should repeat these observations a few months later we should find that the pole had wandered away to some distance. To be sure, this distance would not be great and all the wanderings of the pole that have thus far been observed could be plotted to true scale on the floor of a room not much larger than the one we are in. Of course if the pole is moving, so too is the earth's equator; and thus the latitudes of all points on the earth are varying. Such wanderings as these need not disturb the peace of mind of those gentlemen who like to discover the arctic or the antarctic pole. Under the circumstances that the polar explorer must work and with the meager instruments he can transport, he is glad to determine his latitude within half a mile of the truth.

We must understand that it is only in our time and only after the lapse of many years since Euler published his memoir, that latitude variations have actually been observed. There was nothing in Euler's theory to indicate how large a variation to look for, since this is a matter that depends upon the whole complex of "initial conditions," of which our knowledge is the very vaguest. But this theory does tell us what the period of the variation should be, since this depends upon the shape of the earth and the distribution of the material within it, and precisely the information that is here needed is afforded by a study of precession. Applying this information Euler was able to say that the period of the latitude variation should be ten months. Bessel at Königsberg in 1842, later Peters at Pulkova, Nyren also at Pulkova, Downing at Greenwich, and Newcomb at Washington, all searched their observations for evidence of a latitude variation having a period of ten months, but all in vain. Astronomers concluded that if latitude variations existed at all, their extent was too small to be detected by instruments of the precision that had then been attained.

Toward the end of the nineteenth century vague whisperings that this conclusion might be incorrect seem to have been in the air. But the first clear word to this effect came in 1888 from the lips of Küstner at Berlin. He had invented and applied a method for determining the amount of the aberration of light; but he found that his observations gave well-nigh impossible results, agreeing neither among themselves nor with earlier reliable observations. By a nice chain of logic he was able to exclude one possible explanation after another until there was left only the supposition that the latitude of his station had changed while his observations were in progress. Next he examined nearly contemporaneous observations made at other places, and when he found that he could account for certain puzzling discrepancies, he no longer hesitated to announce that latitudes were variable after all.

This announcement awoke the liveliest interest and encountered no little scepticism. Special observations were at once set on foot at various observatories in Europe and America, as well as at a station near Honolulu in the Sandwich Islands. These islands are

about opposite in longitude to the European stations, and this was the reason for establishing a station there. For obviously if the pole is really changing its place then the changes in latitude for two opposite stations will be the reverse of each other. When in 1893 this was found actually to be the case, other possible explanations for the observed phenomena at once fell down, and latitude variations became for the first time a universally accepted fact.

Much time and effort have since been expended in attempting to formulate the "laws" of latitude variations and to give them a mechanical interpretation. But observation has shown that the variations are of unexpected complicity, and as a consequence we are still very far from having satisfactory knowledge of this subject. By the same token it is probable that an intensive study of these variations, particularly from points of view other than the astronomical, will teach us much concerning the interior of the earth as well as some of its surface phenomena.

It was the late Dr. Chandler, of Cambridge, Massachusetts, who took the lead in investigating the nature of latitude variations. By overhauling ancient observations (made of course without any reference to the present subject) he was able to trace the presence of the variations back to the time of Bradley in the middle of the eighteenth century. Thus it happens that at the very time that Euler was writing the first theoretical paper on the subject, Bradley had already begun making the observations from which the actual existence of latitude variations might have been proven at once. Chandler was able to gather similar evidence from other miscellaneous series of observations and thus to set down a tolerably continuous record of the variations during a century and a half. However interesting a fact this may be from an historical point of view, it does not help very much in a practical study of the subject. There are two reasons for this: first, it is only for European stations (and for the most part only for Greenwich) that we have any knowledge of these earlier variations; the other component of the wanderings of the pole, namely that in the meridian at right angles to the meridian of Greenwich, did not begin to be known until very recently. Again, these ancient observations were undertaken for

certain definite purposes that they served as well as could be expected for their time; but they were not intended and are not well suited for precise determinations of the latitude. Close acquaintance with the subject has taught us that exceedingly delicate observations are necessary to define the variations with adequate accuracy. If I held in my hands two plumb lines half a meter apart, they would not be quite parallel to each other, though both are exactly vertical; if they were prolonged, they would meet somewhere near the center of the earth, 4,000 miles below. The angle between them is a little less than $0''.02$ and represents approximately the accuracy that is demanded and that has recently been attained in latitude observations. This success is due chiefly to the International Geodetic Association which has organized an "international latitude service" of high efficiency, and to whose efforts and experience are due the improvements in instruments and methods that have made possible this extraordinary degree of precision. Since 1899, the Association has maintained six observing stations for this sole purpose, two of these being in our own country. One of the minor effects of the war that is now raging in Europe will be the discontinuance of some of these stations. One of the American stations has already been abandoned and the same fate will overtake the other in June, 1916, unless some independent means of maintaining it, at least temporarily, presents itself soon. An interruption of these observations would be a great pity, for this is one of the cases where a continuous record is highly desirable.

To return to Chandler and his work on these variations, perhaps the most important of his achievements was to show that the principal term in the variations, instead of having a period of ten months in accordance with Euler's theory, has in reality a period of fourteen months. This difference explains the failure of Bessel and all the others who preceded Küstner to find a latitude variation in their observations; for, relying upon Euler's results, they had all tested their observations for the ten-month variation and had sought for no other variation. For the same reason, Chandler's announcement of the longer period was received with incredulity in some quarters, and this feeling did not vanish until Newcomb

pointed out that Euler had made a certain assumption regarding the interior of the earth that had in the meantime been universally discarded; his period of ten months applies in fact only to a perfectly rigid and unyielding earth. Newcomb showed that if the earth yields to deformation to the same extent as though it were composed throughout of steel, then Euler's period would be lengthened to about fourteen months. Here we have the first dependable determination of the rigidity of the earth, a result that has since been confirmed in several ways, particularly by a measurement of "bodily tides" in the earth.

The fourteen-month term (or the modified Eulerian term as it is now called) has been under accurate observation for a quarter of a century. The period can probably (though not certainly) be regarded as constant. This is what we should expect, for a change in this period would call for a sensible alteration in the distribution of the material within the earth, or a change in the rigidity of the earth. The amplitude of this term presents a very puzzling problem. Its usual value is about 0″.27, but twice in recent years it has jumped to about 0″.40. Such a change could be accounted for by supposing that the earth had received a severe blow or a succession of milder blows tending in the same direction. We are reminded that both Milne and Helmert have suggested that there might be a direct connection between latitude variations and earthquakes. This suggestion was originally made by Milne very early in this century when the astronomical data necessary to test it were still very meager. It is to be hoped that the question will be taken up again in the light of the information that has been added during the past ten or twelve years.

Though the Eulerian term is the largest part of the latitude variation, it is by no means the only important one. We have next an annual term with a maximum amplitude of about 0″.20. We may say with some confidence that this term is seasonal and meteorological in its origin, but at present no more definite statement would be warranted. It was early suggested that ocean currents might cause this variation. These currents would have to vary greatly with the season, either in the volume or the speed of the flow, or in

its direction; for an unvarying current would merely modify the Eulerian term once for all and would leave the latitude variations otherwise unchanged. A similar suggestion has been made with regard to air currents, and appeal has also been made to unequal deposits of snow and ice on two opposite hemispheres of the earth, to account for the annual term. It seems to me that these explanations have not been subjected to the critical numerical tests that are possible and desirable. The meteorological data are doubtless competent to enable us to compute at least the order of the effects in the latitude variations that we should expect from these various causes. Furthermore the annual term is probably variable in its amplitude, and it is important to ascertain how (if at all) these changes are related to the corresponding meteorological observations.

One other term must be mentioned in this brief summary. A few years ago Kimura of Japan made the important discovery (the most striking contribution to astronomy that has ever come out of Asia) that the latitudes of all stations are affected by a variation that does not depend upon the longitude but which is the same for all points in the same latitude. In other words there is present a variation that is not due to the wanderings of the pole. To ascertain more closely the nature of this term, the International Geodetic Association extended its latitude service temporarily to the southern hemisphere, with the result that the term was found to be of precisely the kind that would be caused by an annual wandering of the center of gravity of the earth to and fro along the axis of rotation. This must be regarded merely as an illustration and not as an explanation, for so great a change (about three meters) in the position of the center of gravity is excluded on other and very conclusive grounds. No plausible explanation for the Kimura term has as yet made its appearance, and as a consequence the reality of the term has been questioned from every possible point of view. Many explanations have been advanced, each of which sought to account for the term as merely an instrumental effect or the like, just as was the case twenty years earlier with the whole of the latitude variation itself. Against such attempts the Kimura term has

held up very well. It is not too much to say that at the present time all but one of the numerous explanations of this class have been disposed of; this exception deserves a brief mention, particularly as it calls loudly for the attention of the meteorologist. Let us suppose that the layers of equal density in the atmosphere above a station are not horizontal, but that they are sensibly inclined. If this occurs without our knowledge, as it would under ordinary circumstances, then we should apply refraction to our observations in a slightly erroneous way and we should derive a value for the latitude that is not quite correct. Let us suppose further that this effect were a world-wide one and that in any given month there would be a pronounced tendency for the inclination to be in the same sense in all latitudes, north and south, as well as in all longitudes. Then we should have a set of circumstances that would account for the Kimura term as an atmospheric effect, and therefore it would be excluded as a real variation of latitude. So far as the astronomer is able to testify, the evidence is against the occurrence of such tilts in the atmosphere. The inclination required to account quantitatively for the amplitude of the Kimura term is over two minutes of arc, or a slope of about one part in fifteen hundred. Presumably in a few years we shall be able to say something more definite as to the possibility of the existence of such conditions. My own opinion is that this explanation, like so many others of similar character that have been suggested for the Kimura term, will be found untenable. Further I venture to think that latitude variations as a whole will find their explanations less on the surface of the earth and more in its interior than seems now to be the generally accepted opinion.

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A PRACTICAL RATIONAL ALPHABET.

By BENJAMIN SMITH LYMAN.

(Read October 1, 1915.)

How to reform English orthography, and reduce it to simple regularity is an interesting problem. Repeated efforts have been persistently made in that direction. Among others, overhasty enthusiasts, in their disgust at the irregularities and phonetic inadequacies of the established English spelling, have insisted that a comparatively few of the most glaring irregularities should be "simplified" at once, hoping that later on another larger batch of "corrections" may be adopted. Of course, such alterations from the established usage can only come gradually into general, or established, use; not in less than fifty or seventy years, as may be seen in the few small changes urged by Noah Webster. Meanwhile, if the alterations meet with somewhat wide acceptance, there must be, on the whole, very greatly increased irregularity in English spelling, approaching, indeed, chaotic lawlessness. The repetition, and thereby prolongation of this painful unruly condition of our orthography in such an ill-considered effort at reform must remind one of the pretended humanity of cutting off a dog's tail by stages of an inch at a time. Would it not be far better to devise a practical and thoroughgoing system of orthography to be used alongside of the present established usage; and to become more and more used, until at last, it may become altogether adopted and universally used?

There are serious difficulties, however, in setting up a practical and thoroughgoing system of orthography. Any plan of reformed orthography should never fail to keep in mind the necessity of being thoroughly practical, if the least hope be entertained of its coming into universal, or even common, use. The great, widespread vogue of the Roman alphabet is doubtless due to its even rude simplicity; and in many hundred years it has been impossible to introduce into general use more than a very few extremely simple modifications of

the original forms of the letters: as for instance the carvilium to distinguish G from C and the distinction between J and I and between U and V, which appear to be still struggling for complete prevalence. It may, however, be borne in mind that notable additions to the Arabic alphabet have been made and accepted in order to express additional sounds in Persian or other languages: but it is noticeable that such added forms are strictly in keeping with the original character of the alphabet. The Russians have also strongly modified the Roman alphabet, and not always quite in keeping with the rude simplicity of its general character; yet have established its use throughout a great empire. In proposing new forms of letters for newly distinguished sounds, it is certainly advisable to maintain some restraint upon one's fancy, to adhere to the utmost simplicity, and to depart as little as possible from the general character of bare simplicity of the Roman alphabet, making use, so far as possible, of old devices, and putting forward as few novelties as possible, to be learned and made familiar. It seems highly desirable to avoid the use of altogether outlandish forms like the fully obsolete old Anglo-Saxon letters, wholly out of keeping with our modern alphabet; or to offend the eye by intermixing italic letters with Roman and by other tasteless similar devices, or by interspersing inverted letters, though to be sure of good Roman shape. Above all, however, let us avoid separate diacritical marks to distinguish sounds, marks that are a nuisance to write, an obscurity to read, and by their occasional forgetful omission a fruitful source of misleading. Especially the use of diacritical marks in a way opposed to their time-honored significance, is to be reprehended; as for example, the use of an accent to indicate merely the length of a vowel. Such practice has misled commonly into various errors of pronunciation of some oriental words. We shall see if there be any serious difficulty in getting handsomely along without any of those hastily, inconsiderately adopted, tempting, shallow, easy, but terrible, makeshifts. There are some restraints, or guides, which must cogently influence our choice of letters or symbols to be used in indicating the different sounds of the language. It is highly desirable, or absolutely necessary, that each sound should be indicated by only one letter, and that each letter should have but one sound; and it would

be absurd to acknowledge that principle, and then as in Volapuek and Esperanto, at the very outset give to *z* the sound of two letters, *ts,* merely because it happens to have those sounds in German. Another important principle is to give to letters or devices the force that they already have, and long have had, in the languages where they have been in use. In general, the customary practice of the majority should have sway, requiring the minimum of new learning. As English is far and away the most numerously spoken language throughout the world, the sounds to be attributed to the consonant letters should be as in English; though, owing to the extreme irregularity and variety of the English vowel letters, they must give place to letters that are more prevalent in the other European languages. The English consonant *y,* for example, should be used; not, as in Esperanto, the letter *j,* which has that sound among the comparatively small number who use German and Italian. In Volapuek, *j* is made to serve for the English *sh,* a most unheard-of use.

In English, the combinations *ch, sh, th* and *wh* each is used for a single sound, and it is desirable to substitute for it a single letter. Would it not be highly practical to write those sounds by means, in each case, of merely the first of the two letters with a subscript small appendage somewhat similar to the old device of the French cedilla, though a little different in form, to represent the letter *h,* and having a more or less distant resemblance to it in shape? In cursive writing, the resemblance to an *h* need not by any means be close, and may be really abbreviated, as there would be no danger of misunderstanding. We have, thereby, four new characters with but a single device to remember, and that not a new one, and the new forms are entirely in keeping with our old alphabet and with already customary methods. As to the sound of *ch* in *church,* it is sometimes maintained that it is in reality a sound compounded of *t* followed by *sh.* But that is clearly an error; for even the ear can distinguish a difference in the sounds, and the sound of *ch* is as distinctly different as is the sound of the opening or closing of a somewhat tightly swollen door, compared to the mild clapping to of a well-fitting closure. The peculiarity of the contact of the tongue and roof of the mouth, with the consequent vibrations of the roof of the mouth, occasions a peculiar sound different from *t* and from

sh. A corresponding difference occurs between the sound of a smack with the lips and *p* or *b*. The sound of *zh,* as in pleasure, would, of course, be indicated by *z* with a subscript *h*. If it be desired (unlike ordinary English) to distinguish the sound of *th* in *this* from that in *thin,* the logically analogous and simple mode of writing it would be with a *d* with a subscript *h*. The whispered, or surd, *y,* heard in the word *hue,* might also be indicated by a *y* with a subscript *h*. The guttural sounds indicated in oriental transliteration by *kh* and *gh,* would likewise be represented by *k* or *g* with a subscript *h*. Until types of these new forms are to be had, we may provisionally, instead of the subscript *h,* use a small *h* at the side: c_h, s_h, t_h, d_h, k_h, g_h, w_h, y_h. The simple sound written in English with *ng* should be indicated (as proposed so long ago as Benjamin Franklin) by a character similar to a *g* but with the upper part in the form of an *n,* for which there is already type.

Other consonant sounds, the so-called cerebral sounds, occurring, for example, in the Sanscrit and in the dialect of Peking, could be simply indicated in a similar manner, by giving to the upper part of the corresponding letter the shape of an *r*; since those sounds are made with the tongue rolled up, as for an *r*. In Sanscrit, such a modification of *sh* occurs and in the Peking dialect *y'* is so pronounced, with the tongue rolled up, and may be indicated by a *y* with the upper right hand fork in the shape of an *r* (provisionally *s*;„, and y^r).

With these four or five simple characters, we have then a full supply of consonants without going outside of the ordinary English usage; *b, c, ch, d, dh, f, g* (always as in *give, get*), *j, k, l, m, n, p, r, s, sh, t, th, v, w, y, z, zh;* omitting *q,* and *x,* as superfluous; and using *c,* only with the subscript *h*. Indeed as the *c* is only so used, even if the subscript *h* should be omitted there would be no danger of confusion, and *c* would have before all vowels the same sound that it has in Italian before *e,* and *i*. *H* is sometimes reckoned as a consonant, but, of course, erroneously, as it is the whispered form of the vowel that follows it.

As already intimated, order out of the chaos of English vowels is only to be attained by adopting the more uniform practice of the European continental countries, with *a,* as in *arm, o* as in *note, u* as

in *rule*, *i* as in *pique*, *e* as in *they;* and, for the vowels, we must abandon the hope of indicating by a separate character every one of the infinite number of shades of sound, a few of which occur in such series of vowels as in: *hate, hale, hare, hairy, Harry, hal, hat.* The progress of enlightenment in thousands of years has led to far greater nicety of distinction in vowel sounds than was common formerly. But instead of five or six vowels that it was then found worth while to indicate by separate characters, it would now be hardly practical to have distinct letters for more than eighteen or twenty vowels and that number may be very practically arranged.

A difficulty in bringing into general use any such somewhat nicely adjusted system of indicating the sounds, especially the vowel sounds, of any language is that the pronunciation of words is different in different regions and even among different families and individuals of the same region; nay, even with the same individual according to varying emphasis in different connections, as *to* in "going to Boston," and "to and fro" and the pronunciation sometimes varies through slackness or slovenliness of articulation or enunciation, as in substituting a slight vowel sound for the consonants *y* and *w* in such words as *they* and *snow,* or in dropping *r* altogether after a vowel and before a consonant, as in *arm*. Hence strict regard to phonetics would give the same word several different forms according to the taste or habits of different writers, and stand seriously in the way of the uniformity of spelling that would be extremely desirable for at least a literary language to be used in common by a numerous people.

As regards the vowels Professor Samuel Porter over forty-eight years ago, in the *American Journal of Science,* September, 1866, excellently classified the readily distinguishable vowel sounds of English and other principal European languages, and arranged them according to their physiological mode of formation, with a simple illustration indicating nine different parts of the mouth where the tongue is placed to give the form of cavity, which with the issuing breath, will produce each vowel sound. So simple are the plan and the illustration that they have been perfectly successful in inducing very ignorant Orientals (in India and China) to indicate thoroughly and simply the mode of formation of some of their most

peculiar sounds, which to ordinary foreigners without Porter's help, and with merely the ear as a guide, are mysterious and even considered quite unattainable. He distinguishes nine points at which the tongue is placed, and at each of those points, four degrees of openness; making thereby thirty-six readily distinguishable vowels. But a number of them are not in ordinary use, and are therefore not to be considered in any orthographic scheme. A few additions are to be made on account of the effect of stiffening the lips, changing the sound. In order to accommodate ourselves to this classification of the vowels it is desirable to add to our letters æ (not a new combination) as ae in German *Maedchen,* for the sound of *a* in *care;* and oe (again not new), nearly like the oe in German *schoen* for certain closely allied sounds; and a new character, like the Swedish *a,* with an *o* over it; but contracted into a single form, for the sounds, like *a* in *war,* or *o* in *lord,* or *oa* in *broad.* Yet another new form may be added, *e* with a stroke like an accent just to its left, to correspond with the French acute-accented *é.* We have, then, nine characters for Porter's nine groups of four vowels each. He calls attention to the fact that in each group of four vowels, differing only in the degree of closeness of the tongue at the same place in the mouth, two of the four are long and two short. Let us therefore represent the long vowels by the ancient device of simply doubling (with slight contraction) the letter used for the short vowels, as the Greeks already set us the example with their omega. All the vowels can in like manner be doubled, and somewhat contracted, making at once eighteen easily written and easily read vowels conforming well to the already established character of our alphabet. Until appropriate type for the purpose are to be had, we might provisionally merely double the present letters; as: aa, ee, etc. In one or two cases the number can be increased by indicating a labial modification of the vowel by means of a small upright stroke, an abbreviated *l* (provisionally a small *l*), close to the right hand of the letter. In this way, we are easily provided with about twenty vowels, apparently an ample supply for the English language.

Let us now consider the vowels one by one, more particularly. In group I, the *a* of *last, ask, chant,* is short; while that of *father*

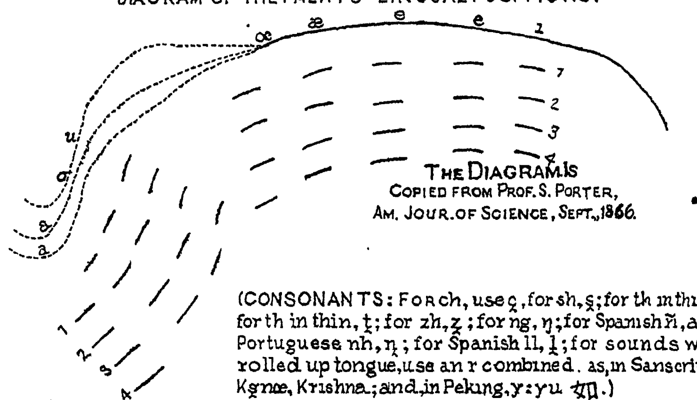
and *calm* is long; and that of *baa, ah, arm, charge* is still broader. The two last would therefore be written with a double letter (provisionally aa); and there would be no need to distinguish in writing between these two, because there is distinction enough in the following *r* or *h*.

In group II, the two closer vowels, as (long) in *war, lord, awe, pause,* or (shorter) *all, water, long, daughter,* are both labially modified, by stiffening the lips; and can be so indicated by means of a small upright stroke (an abbreviated *l,* provisionally a small *l*) just to the right of the letter. The longer vowel can be indicated by doubling, as already described. The shorter and not labially modified vowel of the second degree of openness is heard in the words *salt, although, cross, horror;* and the third degree of openness, also not labially modified, occurs in *sod, nor, off, what, knowledge;* and may be written with an *a* combined with an *o,* like the corresponding Swedish letter, but more contracted. These two closely similar vowel sounds, scarcely distinguishable by ordinary ears, it seems hardly worth while to provide with separate letters (though the distinction of the third degree might be marked by a small 3 just to the right of the letter). The fourth degree of openness does not occur in ordinary speech.

In group III, in like manner, the least open vowel, as in *note, toe, low, loaf, door, mourn,* being longer, may be written with a double letter (like the Greek omega), or, provisionally, by a repetition of the single letter, *oo*; and might be marked as labially modified, in the way already indicated. But this is hardly necessary, because, in English, it always has that modification, making it unnecessary to mark it. The next degree of openness is likewise always labially modified, and being short would be written with a single letter. It is also distinguished by being an unaccented vowel. The third degree of openness, as in *not, dot, folly, knock, proper, bite, eye* (*oy,* a short *o* followed by the consonant *y*) occurs only in accented syllables, and is thereby sufficiently distinguished.

In group IV, the long sound of the vowel in *rule, sure, fool, pool, moon, shoe, soup,* would be written with a double vowel (provisionally by *uu*), while the vowel of the second degree of openness, as in *full, pull, bosom, woman, should, good, foot, book,* would be

DIAGRAM OF THE PALATO-LINGUAL POSITIONS.



(CONSONANTS: FOR ch, use ç, for sh, ş; for th in this, ḑ
for th in thin, ţ; for zh, ẓ; for ng, ŋ; for Spanish ñ, and
Portuguese nh, ŋ̧; for Spanish ll, ļ; for sounds with
rolled up tongue, use an r combined. as, in Sanscrit, ş̣:
Kşnœ, Krishna; and, in Peking, y: yu 女𠘨.)

VOWELS·

I A, Æ, a, aa, ɑ, ɑɑ, A, Æ
1. as in last, ask, chant: last, ask, çant.
2. as in father, calm: faather, kaam.
3 as in baa, ah, arm, charge: baa, aa, aarm, çaarj
4. (Not in good English.)

II. Ʌ. Ʌ, ɐ, ɐɐ, Ʌ, Ʌ, ɐ. ɐɐ.
1¹ as in awe, war, lord, pause: ɐɐ, wɐɐr, lɐɐrd, pɐɐz, (labially modified—lips stiff).
2¹ as in all, water, long, daughter: ɐl, wɐter, lɐng, dɐter, (labial)
2. as in salt, although, cross, horror: salt, alḑo, kras, harœr.
3. as in sod, nor, off, what, knowledge: sad, nar, af, what, nalej.
4 (Not in good English.)

III. O, Ꞷ, o, ꞷ, O, Ꞷ, ơ, ꞷ.
1¹ as in note, toe, low, loaf, door, mourn, beau. nꞷt, tꞷ, lꞷ, lꞷf, dꞷr, mꞷrn, bꞷ.
2¹ as in opinion, agony, propose, mellow: opinyœn, ægone, propꞷz, melo (unaccented).
3. as in not, dot, folly, knock, proper, eye, bite: not, dot, fole, nok, propœr, oy, boyt
4. (Not in good English.)

IV. U, Ɯ, u, ɯ, U, Ɯ, u, ɯ
1. as in rule, sure, fool, pool, moon, move, shoe; rɯl, şɯr, fɯl, pɯl, mɯn, mɯv, şɯ.
2¹ as in full, pull, bosom, woman, should, good: fʊl, pʊl, bʊzœm, wʊmœn, şʊd, gʊd.
3. as in fulfil, willful: fulfil, wilful—(unaccented).
4. (Not in good English)

V. Œ, Œ, œ, œ, Œ, Œ, œ, œ.
1. (Not in English—the German ö, French eu.)
2. as in girl, virtue, mercy, myrtle, earl: gœrl, vœrtyu, mœrse, mœrtl, œrl—(before r).
3. as in up, but, cousin, rough, dove, done: œp, bœt, kœzin, rœf, dœv, dœn.
4. as in burr, church, work: bœr, çœrç, wœrk—(before r, accented).

VI. Æ, Æ, æ, ææ, Æ, Æ, æ, ææ.
1. as in their, fair, parent: ḑær, fær, pærent.
2. as in care, there, prayer, hair, pair: kær, ḑær, prær, hær, pær—(before r).
3. as in cat, man, sad, hap: kæt, mæn, sæd, hæp—(accented, no r).
4. (Not in good English.)

VII. E, E, e, e, E, E, e, e.
1. as in they, grey, vein, great, name, fate: ḑey, grey, veyn, greyt, neym, feyt.
2. as in nitrate, climate: noytret, kloymet—(unaccented).
3. as in get, egg, red, mend: get, eg, red, mend—(accented).
4. (Not in English.)

VIII. E, e, E, e.
1. (Not in English—the French é.)
2. as in guinea, valley, carried, city: gine, væle, kæred, cite—(unaccent'd).
3. as in goodness, college: gudnes, kalej—(unaccented).
4. (Not in English.)

IX. I, I, i, ii, I, I, i, ii
1. as in pique, machine, field, eat, eve, deep: piik, maşiin, fiild, iit, iiv, diip.
2. as in divine, vehicle, mandarin: divoyn, viihikl, mændarin—(unaccented).
3. as in pin, hit, sin, will: pin, hit, sin, will—(accented).
4. (Not in good English.)—(The French u would be ɯ.)

(Until proper type can be had, use double letters for long vowels.) B.S.L.

written with a single letter. Both these vowels are labially modified, and might be so marked, in the way already indicated, but it is unnecessary so to mark them, because there is no vowel in English with which they could be confounded. In the third degree of openness, the unaccented vowels in *fulfill,* and *willful,* occur; but (written with a single letter) are sufficiently distinguished by the absence of accent. The fourth degree of openness does not occur in good English.

In group V, the first and second degrees of openness, occur in the German oe, and the French eu (nearly, though not quite, the same); but not in English. The second degree of openness without labial modification occurs in English only before *r* as in *mercy, virtue, girl, myrtle, earl, pearl, earth;* and may be written with a single letter (œ). In the third degree of openness, likewise short, and to be written with a single letter, occurs the so-called natural vowel, accented, and without *r,* as in *up, but.* In the fourth degree (written with a double vowel), long, occurs before *r* the vowel sound of *burr, occur.*

In group VI, the long sound, with a double letter (provisionally, the single letter repeated, æ æ), is heard as the *a* in *parent, ei* in *their, ai* in *fair.* It is the German *ae* in *Maedchen,* and the French *è* in *après, scène, père.* The second degree of openness, with a single letter, is heard in *care, there, prayer, heir, pair;* in each case followed by the sound *r.* Without that sound of *r,* the third degree of openness gives us, with the same letter, the *a* in *at, cat, man, sad, hap.* The absence of the *r* makes it unnecessary for them to distinguish the two slightly different vowels.

In group VII, the first degree of openness with a double letter, or, provisionally, the single letter repeated, *ee,* gives us the *e* in *they, grey,* and the like sounds in *fate, name, great, vein, hail, pay;* the German *mehr, jeder, ledig, See.* The second degree of openness, with a single letter, gives us the *a* of unaccented syllables, as in *nitrate, climate.* The third degree of openness, with the same single letter, occurs in accented syllables, as in *get, egg, red, mend.* The fourth degree does not occur in English.

In group VIII, the first and fourth degree of openness do not occur in English. The first one, to be written with a double letter,

occurs in the French acute-accented *é* and *ai*. The second degree of openness (written with a single letter, provisionally, ¹e, an *e* with a small upright mark, or figure 1, above at its left) occurs in English in unaccented syllables only, as in *guinea, valley, carried, city.* The third degree of openness (likewise a single letter) differs so slightly from the second as hardly to need a separate character, though it might be marked with a small abbreviated 3 put to the right and upper part of the letter *e*. It occurs in the unaccented syllables *goodness, college.*

In group IX, the first degree of openness, to be marked with a double letter (provisionally, *ii*), is found in the *i* of *pique, machine.* When this is labially modified by stiffening the lips, it becomes the French *u,* as in *ruse,* and the German *ue,* as in *ueber,* to be marked with a small stroke, an abbreviated *l,* at the right of the letter. The second degree of openness, to be marked by a single letter, occurs in unaccented syllables as in *divine, vehicle, mitigate.* The fourth degree of openness does not occur in English.

We have, then, for the vowels nineteen letters; distinguishing all the readily distinguishable vowels used in English. In two or three cases the distinction is indicated by the accent as in certain unaccented syllables, as in *fulfill, goodness;* and in other cases by the subsequence of the sound *r,* as in *girl.* Even these slight differences could be indicated by a scrupulous writer with an abbreviated figure *3* alongside, to the right, and at the upper corner, of the letter.

Having thus made possible the writing of English with unmistakable letters, each letter for a single sound, and each readily distinguished sound by a single letter, a strong reason is advanced in favor of the general adoption of English as a universal language. Indeed, it is ardently to be hoped that eventually some one language may become universal, and known to the whole human race. Latin was formerly so widely known and extensively used among the more civilized nations as to give some color to its claim to become the universal language. But the gradually increased refinement of ideas in modern times has apparently made it impossible to be satisfied with so bald and rude a method of communication. The numerous artificial languages proposed for this purpose, even if not

liable to the same objection, or to greater crudity, are yet additional languages to be learned. English already known to a much larger number of men than any other language, seems to be, by all odds, the best adapted to become, perhaps with slight modifications, a universal language. The simplicity of its grammar, aside from orthography, makes it remarkably easy for foreigners to learn; and, for use in universal form, the comparatively few irregularities of grammar might considerately be eliminated, so that (in universal form) it might be allowed to say mouses, instead of mice, and digged instead of dug. English has already shown its capacity to express perfectly the finest distinctions of ideas and must in that respect far excel any artificial language, like Esperanto, or Volapuek, with their rude, bald, lack, for example, of the definite or indefinite articles. A rational, phonetic, practical spelling would, then, make English ideally perfect for a universal language. Clearly, for that purpose, the usage of speakers of some region, or of some degree of cultivation, with some degree of emphasis, must be selected as the norm to which the written language should conform, in order to make the writing and spelling in the main, though not always in every minute detail, phonetic. Well taught children should, then, everywhere learn to pronounce the words as they are spelled, and not be allowed to drop the sound of *r* in arm, or pervert the sound of the English long *u* (like *yu,* except after the sound of *ch, j, r, sh, zh,* or *y*). Normal schools should train teachers in these details so that the children may be properly drilled. In that way the language would be rightly conserved, and would tend to become fit for universal use.

One serious difficulty in the adoption of any such improvements of our alphabet is that there are so many men who excel more in persuasive eloquence, in "the gift of the gab," than in a thorough knowledge of phonetics and inclination to careful reflection. Cadmus could not have been a ready tongued, shallow utterer of rapidly up-bubbling superficial thoughts. A group, or committee, or society of such quick-witted individuals (perhaps some of them so densely ignorant as to suppose *h* to be a consonant, instead of the whispered, or surd, form of its following vowel, or to insist that the English *ch,* and *j* are compounded of sounds distinguishable even by the ear, and as much unlike the real ones as the bursting open, or banging shut of a tightly swollen door, is to the mild clapping to or open-

ing of a well-fitting closure), may make bold to put forward by their majority vote some alphabetic, or orthographic, system (as the Japanese Roman Letter Society did), and may really delay for a long time the adoption of an altogether rational and practical method. It would be much better for individuals to propose their own plans, and put them into use by themselves and by a portion of the public. Gradually, the best of such plans would take the lead, and come into more and more general use, without having to overcome at the outset the prestige of the dominant approval of a high-sounding society or committee. In any case, it would clearly take many years for such a rational new system fully to supplant the present established usage.

Meantime, it might be advisable to do something towards simplifying the learning of the present established spelling. To be sure, the difficulty of learning it has been much exaggerated, owing to the general extreme neglect of the study. It seems, however, possible that the six weeks or so that appears to be ample for a half-grown boy or girl to learn to spell well might be reduced to a couple of weeks, at most, with a properly arranged booklet; so that the present multitudinous army of typists might readily fit themselves to avoid tormenting their employers by ignorance of so simple an art as spelling.

But however advantageous a simple, purely phonetic spelling might be to a defectively educated typist, or to an adult foreigner, let it not by any means be imagined that the time spent by children in acquiring our more complicated established orthography is uselessly thrown away. On the contrary, it is a highly useful discipline, not only training the memory in a simple way, well adapted to young children, but giving most valuable habits of close and accurate minute observation (the precision that is the most efficient aid to the conservation of language), and enabling the easy understanding and remembering of the proper mode of writing a new word or name. Such habits may also be acquired by certain games of children, but in a way not a whit more interesting or "useful" than the old-fashioned spelling match. The comparatively recent way of teaching to read by the general appearance of the word, and with total neglect of syllabical spelling, is detestable, and produces results that are full of torture and disgust to those who have to listen to such reading.

THE CAMBRIAN MANGANESE DEPOSITS OF CONCEPTION AND TRINITY BAYS, NEWFOUNDLAND.

By NELSON C. DALE.

(*Read April 25, 1914*)

CONTENTS.

I. INTRODUCTION.

This paper is based upon data collected during the summers of 1912 and 1913. The former season, Mr. A. O. Hayes and Prof. van Ingen of Princeton University, while making a study of the general geology, stratigraphy, and palæontology of the shores of Conception Bay, Newfoundland, in connection with the investigation of the iron ores of Great Bell Island, came upon the manganiferous rocks of the Lower Cambrian exposed at Manuels, Topsail, Brigus, and other places. They were immediately struck by the unusual lithological and mineralogical characteristics and by the excellent state of preservation, particularly at Manuels, of what are undoubtedly primary

bedded deposits. Some collections and notes then taken of these interesting rocks were later placed at the disposal of the writer for further investigation. The following summer of 1913, the writer as a member of the Princeton Newfoundland Expedition undertook a more detailed study of these deposits at the various localities where the manganese had been found the preceding summer, and also of a deposit of the same age on the northern shore of Trinity Bay.

There are so few syngenetic manganese deposits which still retain their primary unaltered characters and are found to occur at the same horizon over such a wide area that a somewhat detailed investigation gave promise of yielding results of value. In this paper therefore there has been an attempt to present as comprehensive a study of the manganese of southeastern Newfoundland as our knowledge of this hitherto but little investigated region will allow.

The subject matter is primarily chemical in its nature and the analyses herewith presented are from samples taken from the principal manganese-bearing beds. Many more analyses however could have been made and in fact many more should be made if the deposits are to be seriously investigated for commercial purposes. The analyses of the manganese beds at Manuels, Topsail, and Smith Point, Newfoundland and those of the imported specimens from Elbingerode, Saxony were made by the writer in the chemical laboratory of the geological department of Princeton University.

Because of the impalpable fineness of grain of many of the manganese-bearing beds, the petrographical descriptions of certain of the thin sections can deal only with the larger features such as structure, mineral aggregations, and a few of the larger and observable minerals.

The writer feels particularly indebted to Prof. C. H. Smyth, Jr., for many helpful suggestions bearing upon the chemical side of the investigation, and to Prof. G. van Ingen for unpublished information regarding the stratigraphy and palæontology of this region, as well as for the loan of the locality maps and data for the columnar sections which are the results of careful surveys made during the summers of 1912 and 1913. All photographs and microphotographs were generously contributed by Prof. van Ingen to further the presentation of the results of this investigation.

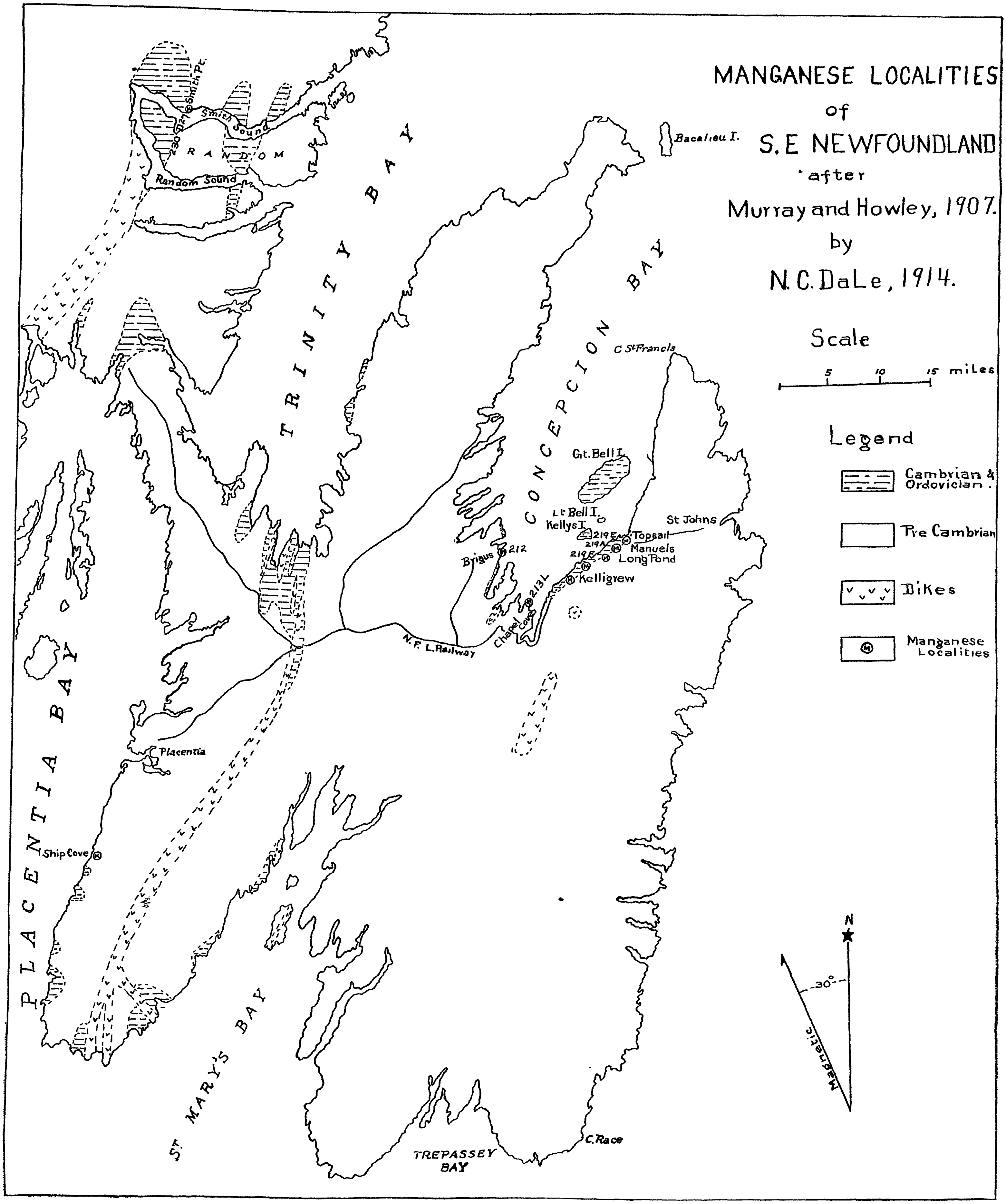


FIG. 1. Map showing manganese localities of southeastern Newfoundland, based on Geological Map of Newfoundland by Murray and Howley, 1907.

II. GENERAL GEOGRAPHIC AND GEOLOGIC RELATIONS OF THE MANGANESE DEPOSITS OF SOUTHEASTERN NEWFOUNDLAND.

Geographic Relations.

The manganese deposits here considered are located in the southeastern part of Newfoundland in the vicinity of Topsail, Manuels, Long Pond, Chapel Cove, and Brigus on Conception Bay, and at Smith Point on Trinity Bay. Manganese is also said to occur near Ships Cove, Placentia Bay. The accompanying map, Fig. 1, shows the approximate location of these deposits.

General Geology.

The sedimentary rocks of this area are included in the Cambrian and Ordovician systems and may be seen on the map (Fig. 1) to occur as irregular patches, the Ordovician composing the larger islands of the bays and the Cambrian occurring as irregular and widely separated fringes resting on the pre-Cambrian of the mainland. The whole series consists almost wholly of shales and thin-bedded sandstones with some limestones, and in the base of the lower Cambrian an occasional conglomeratic bed.

The iron ores of Great Bell Island are Arenig while the manganese and their associated green and red shales are of late lower Cambrian.

Wherever the Cambrian strata have been found in contact with the pre-Cambrian an unconformable relationship exists. The pre-Cambrian rocks of this area as classified by Dr. Walcott (2:219) and by Messrs. Murray and Howley (18:141–154) respectively are as follows:

<table>
<tr><th></th><th>Walcott</th><th>Murray and Howley</th></tr>
<tr><td></td><td>Random</td><td></td></tr>
<tr><td rowspan="4">Avalonian</td><td>Signal Hill</td><td>Avalonian</td></tr>
<tr><td>Momable</td><td></td></tr>
<tr><td>Torbay</td><td></td></tr>
<tr><td>Conception</td><td>Huronian</td></tr>
<tr><td></td><td>Laurentian</td><td>Archaean</td></tr>
</table>

The Avalonian and Huronian of Mr. Howley represent a thickness of 12,370 feet. A later unpublished estimate of 18,250 feet has

been made by Mr. A. F. Buddington, who is studying the pre-Cambrian rocks of this region. A brief description of these formations at this time will be necessary for a comprehensive view of the Newfoundland manganese deposits.

Laurentian: The rocks of this formation are in great part gneissic and granitoid, and are probably the oldest rocks of the area.

Huronian: This formation, which is equivalent to the "Conception" of Dr. Walcott, consists principally of the Conception slates which are of tufaceous marine origin. They are intruded by bosses and dikes of granite, diorite, monzonite, and gabbro, and contain basaltic and rhyolite flows. The Conception formation was estimated by Murray and Howley to have a thickness of 2,950 feet.

Torbay: This formation consists of about 3,300 feet of green and purple slates and argillites.

Momable: An estimated thickness of 2,000 feet of brown and black sandy shales overlies the previous formation.

Signal Hill: Red and green sandstones, conglomerates, shales, and arkoses largely of continental origin comprise this formation, the thickness of which is about 9,000 feet according to an unpublished estimate by Mr. A. F. Buddington.

Random: About 1,000 feet of green and red sandstones and white quartzites with occasional basalt flows comprise this series.

Murray and Howley in their report of 1868 for the Geological Survey of Newfoundland describe the general structural features of the Avalon Peninsula as follows:

"The region in question, in particular, and probably the whole island in general, seems to be arranged in an alternation of anticlinal and synclinal lines, independent of innumerable minor folds, which preserve throughout a remarkable degree of parallelism, pointing generally about N-NE and S-SW from the true meridian, corresponding with the strongly marked indentations of the coast as well as the topographical features of the interior. One such great anticlinal form occurs within the region examined this year, with a corresponding synclinal; the axis of the former was found to be more or less overlaid unconformably by rocks containing fossils of Lower Silurian age, none of which were of less remote antiquity than such as are attributed to the horizon of the upper Potsdam group."

"The axis of this anticlinal runs in a moderately straight line from Cape Pine on the south coast to that part of the Peninsula and coming up from below the Intermediate Series, occupies more or less of the surface from the vicinity of the Renew's Butterpots to the shores of Conception Bay be-

tween Holyrood and Manuels Brook. The newer or Great Intermediate Series which flanks this Laurentian Nucleus, was found on the Peninsula of St. Johns and Ferryland to show a general dip to the eastward although making many minor undulations; while on the Peninsula between Conception and Trinity bays the inclination is reversed, being nearly uniformly westerly, making many repetitions of the same strata however, as on the opposite side of the fold. Corresponding with this great anticlinal, the measure of the Intermediate rocks, as seen at parts of the eastern coast of Placentia Bay, appear, by the generally eastern dip which they present, to indicate the axis of a synclinal trough to run from Trinity Bay in the direction of St. Mary's Bay."

As structural work of a reconnaissance nature only has thus far been published in reference to Newfoundland it is hoped that this most interesting phase of geology of the island may be investigated in the near future. The following locality descriptions will take up briefly these smaller structural features which may serve as a clue to the more general structures of the entire manganese area.

III. GENERAL STRATIGRAPHY

There is very little published information regarding the general stratigraphy of the region under consideration but a few observations made while studying the individual manganese deposits and other information verbally communicated by Prof. van Ingen may be of interest at this point.

One of the most striking features of the manganese deposits is their occurrence at the same horizon in shales of late lower Cambrian age at widely separated points on Conception and Trinity Bays. At each deposit, the manganese zone was found to occur below the Paradoxides zone. At Manuels in the shales directly below the manganese nodular beds, heads of Protolenus harveyi (oral communication by G. van Ingen) were found so that in all probability the manganese beds may be included in the Protolenus zone of Matthews (16: 101–153).

By referring to the columnar sections (Figs. 2, 36, 42, and 44) it is readily seen that the sediments consist largely of shales and limestones and that there is a very decided increase in the total thickness of the beds from Manuels where there are 215 feet between the bottom of the Paradoxides zone and the top of the pre-Cambrian to Smith Point, Trinity Bay, where over 1,000 feet intervene between

the Paradoxides zone and the pre-Cambrian. From the bottom of the Paradoxides zone at Smith Point to the top of the Smith Point limestone according to a calculation based upon a careful stadia transit survey of the shore line (Fig. 43) there is a thickness of 546 feet. The total thickness in the number of limestone beds varies from a few feet at Manuels to 100 + feet at Smith Point. The thickness of the shales at Manuels below the Paradoxides zone is about 200 feet while the thickness of the shales at Smith Point within the corresponding limits is over 400 feet, on the assumption that the Smith Point limestone of Trinity Bay corresponds to that limestone of the Manuels section which is just above the basal conglomerate.

The increase in total thickness of the number of beds from the east shore of Conception Bay to the west shore within the corresponding limits would indicate a deeper portion of the Cambrian sea when the sediments were being deposited. The fact that sediments found below the Smith Point limestone on Trinity Bay are not represented at Manuels would indicate that sedimentation had been going on for a longer time in the western portion of the basin than in the eastern. Whether there actually was a greater amount of sedimentation in that portion of the basin remains to be investigated.

As very little information is at hand with regard to the area of the Cambrian rocks, it is quite out of the question for the writer to attempt to outline the area once occupied by the Cambrian Sea in southeastern Newfoundland. Moreover, it is likewise impossible for the writer to outline the original manganese area as it looked in early Cambrian times. If manganese occurs on the eastern shore of Placentia Bay, as all descriptions of that occurrence seem to indicate, it would seem that the original area of the manganese was approximately 200 or 300 square miles, assuming a more or less oblong shape for the deposit.

Although the basal conglomerate at Manuels is evidence of a definite shore line for the Cambrian sea at that part of the basin, there is also evidence at the other localities examined, where, however, the basal conglomerate is not found in any such large development. There are littoral pre-Cambrian contacts at Topsail, Chapel Cove, and Brigus; all with typical shore deposits.

IV. DETAILED DESCRIPTIONS OF LOCALITIES

MANUELS.—Manganese is found as thin jasper-like bands of green and brown color, as nodular beds, and as argillaceous and calcareous beds interbedded with green and red shales of late lower Cambrian age. This mode of occurrence is very well shown in Manuels brook close by the village of Manuels. The geographic, geologic, and stratigraphic relations are shown in Figs. 1–3. The Cambrian at Manuels consists in the main of shales with thin bedded sandstones with conglomerate and thin limestones at its base and the sediments show practically no metamorphism throughout the series. The strike of the beds is N 82 E (true meridian) and the dip is 10 N. One of the best unconformable contacts in the manganese area is that in Manuels brook at Manuels where the basal Cambrian conglomerate lies upon the Huronian. For a more intimate acquaintance with the manganese occurrence a somewhat detailed description of the stratigraphy, lithology, mineralogy and petrography of the manganese beds and their associated strata will be necessary and therefore the individual beds of the section (Fig. 2) will be described in stratigraphical order.

210 A 1, Basal Conglomerate. The base of the Cambrian at Manuels is made up of coarse conglomerate, eighteen feet in thickness, consisting in the main of boulders and pebbles of igneous character. These boulders at the bottom of the bed, where the base of the Cambrian lies unconformably upon the Huronian, measure in some instances twelve feet in diameter, but they diminish in size toward the top to an inch or less. The matrix, of an arenaceous nature toward the bottom, grades into a more calcareous one at the top where the overlying stratum is a limestone.

219 D 1, limestone. This bed is a bluish, fine-grained to pebbly argillaceous limestone of about 3 feet in thickness. The pebbles averaging a fraction of an inch in diameter are angular to subangular in shape and appear to be of igneous rocks. Pteropod shells chiefly of the genus *Coleoloides* abound. Microscopic examination proves this rock to be a semi-crystalline, fine to locally coarse grained limestone. The texture is very suggestive of organic forms, being an aggregate of elliptical bodies, possibly algal concretions [or "copro-

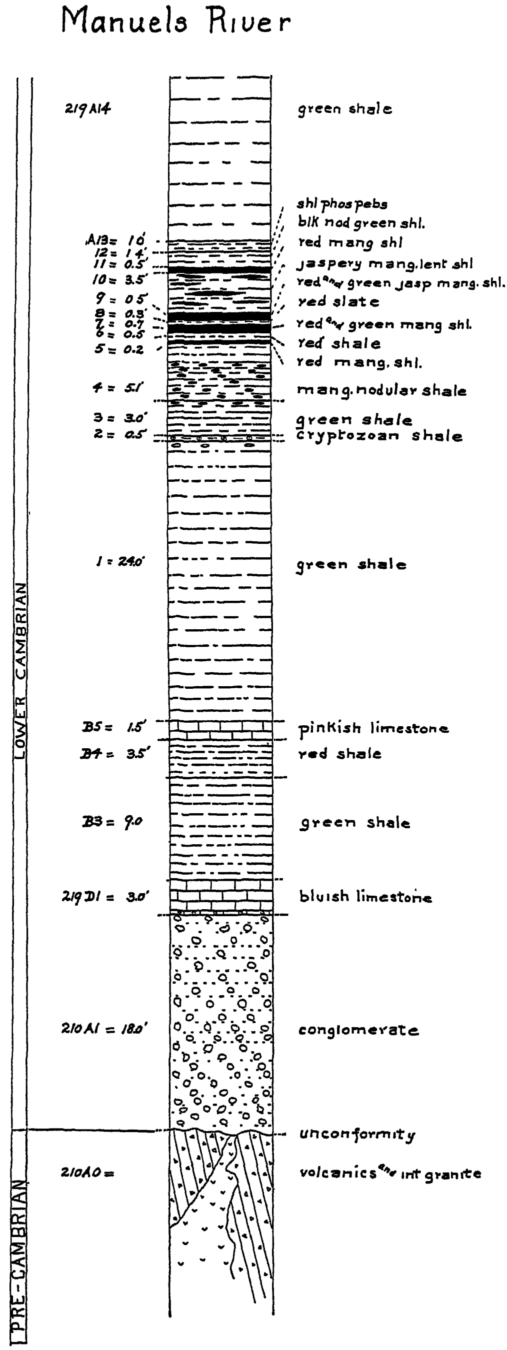


FIG. 2. Columnar section showing the details of the manganese zone in the Lower Cambrian of Manuels brook, 219 A and B.

FIG. 3. View of outcrop of manganese zone of late lower Cambrian age in left bank of Manuels brook.

lite ooze" similar to that described by Philippi from off the Congo mouths—G. van Ingen]. These bodies contain aggregations of carbonate material, probably calcite, which have no definite orientation. The section abounds with pteropod shell fragments, partially replaced with calcite. Calcite and carbonate material comprise the greater portion of the section but quartz occurs as infrequent local segregations and as irregular grains. Pyrite and hematite, as well as a few pink and brown stained areas which are possibly secondary products of manganese and iron, are sparingly present. No analysis was made of this rock but with the sodium carbonate and potassium nitrate bead test a manganese reaction was obtained. This bed is a bluish argillaceous manganiferous limestone.

219 B 3, overlying the limestone, is a brownish weathering olive green shale.

219 B 4 is a bed of red shale, the upper surface of which seems to be limey. The upper 2 inches of this bed has a wavy structure and is somewhat greenish in color. Microscopically the bed is found to be a hematitic shale with occasional grains of quartz and thin rectangular laths of feldspar. Magnetite and pyrite are found as irregular grains in sparing amounts.

219 B 5. With a sharp contact, the red shale is overlain by a 1.5 foot thick bed of nodular and pebbly reddish blue limestone. Because of marked lithological differences this bed has been divided into four smaller subdivisions which are lettered **a, b, c,** and **d.** Subdivision **a** consists of about 2 inches of green shale which is slightly calcareous. Subdivision **b** is a compact pinkish limestone containing pinkish or reddish mineral disseminations and occasional fragments of hyolithid and brachiopod shells. Microscopically this limestone is somewhat granular and crystalline, with calcite as the dominant anisotropic mineral. Quartz occurs occasionally. Hematite as an impalpable dust or pigment is abundant, bordering hyolithid fragments or as irregular accumulations. A fragment of probably organic substance with a cellular structure is a conspicuous feature of the slide. Sponge spicules replaced by calcite are noticeable.

Subdivision **c** differs not very much from the two members described but is nodular or pebbly and much more fossiliferous. Micro-

scopically this rock is a very fine grained semi-crystalline limestone. Calcite, frequently twinned, is the dominant mineral with quartz and chlorite in secondary importance. Barite occurs as occasional small and large irregular grains. Hematite is found bordering calcite grains and fossil fragments or replacing them, and as irregular accumulations. Pyrite is found occasionally. Certain nodular or pebbly forms, isotropic under crossed nicols, are, because of their fineness of grain, of an indeterminable nature.

A very noticeable feature of this section is the diversity of *Hyolithes* forms, some elliptical and concentric and others circular, either entirely or partially replaced by calcite or hematite. The circular forms measure .287 mm. in diameter (Fig. 4, Slide 250).

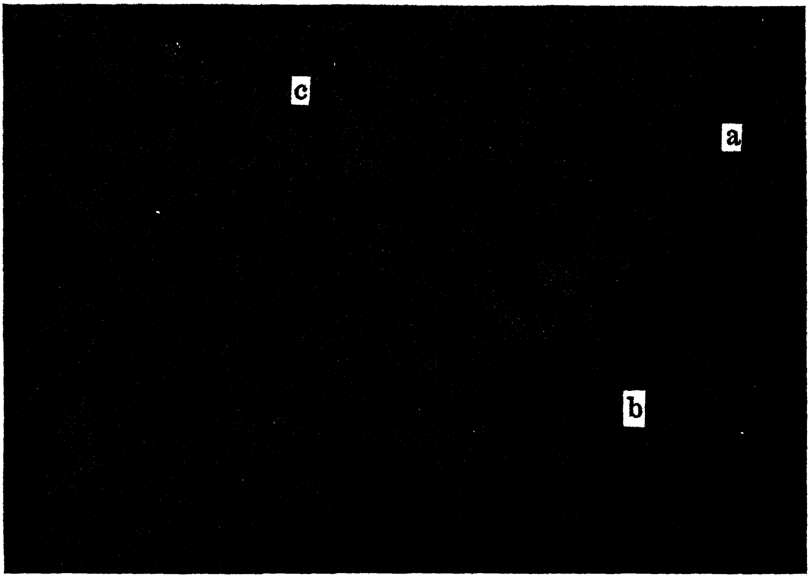


FIG. 4. Microphotograph of limestone, 219 B5c; slide 250; enlarged 22 diam. a, hyolithes with calcite and chlorite; b, calcite; c, quartz.

219 B 5d. The upper subdivision of this bed is of interest mainly on account of the mineral associations in the large nodules on its surface. Differential erosional effects between the limestone and nodule have resulted in a greater conspicuousness of the more resis-

tant nodule. The nodules, measuring as much as 6 inches in diameter, consist largely of argillaceous material, jaspery concentric bands, blades of barite, pyrite and some disseminated manganiferous and ferruginous carbonate minerals which are surrounded by dark areas. These latter are probably manganese oxide zones due to the alteration of a manganiferous carbonate.

Under magnification these nodular portions are roughly concentric and laminated in structure, with laminations red and green in color, and of fine and coarse grain. An oölitic structure, but with the spherules poorly formed, is found in combination with the banded structure. Calcite occurs as somewhat elongated crystals and is the dominant mineral. Wherever the calcite presents the peculiar elliptical and circular shapes mentioned on page —, an organic origin is immediately suggested (Fig. 5 and 6, Slide 254).

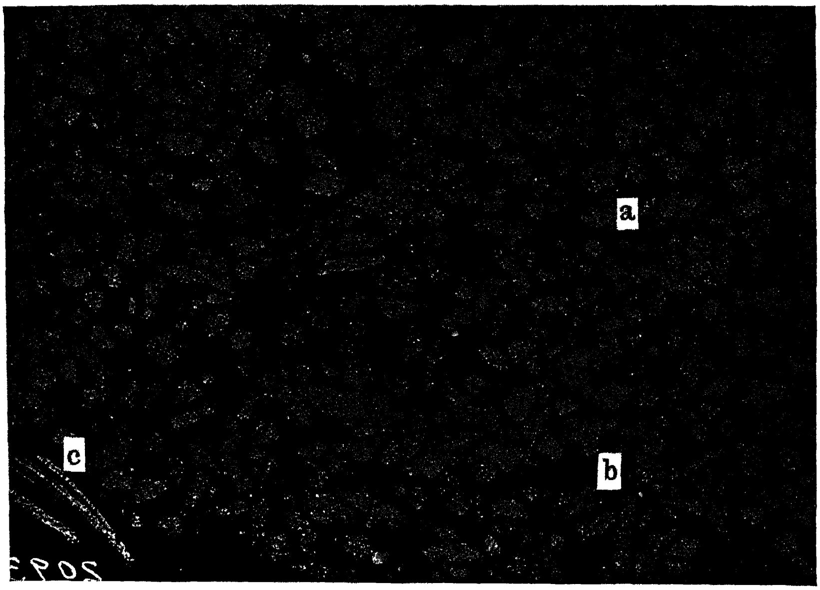


FIG. 5. Microphotograph of limestone, 219 B5d; slide 254; enlarged 22 diam. a, elliptical calcite aggregations; b, chlorite; c, hyolithes.

Quartz is found as irregular grains and aggregations. Barite occurs only sparingly. Among the opaque minerals, pyrite sometimes alter-

ing to limonite, is most conspicuous and occurs as large irregular grains and areas surrounding fossil fragments and associated with

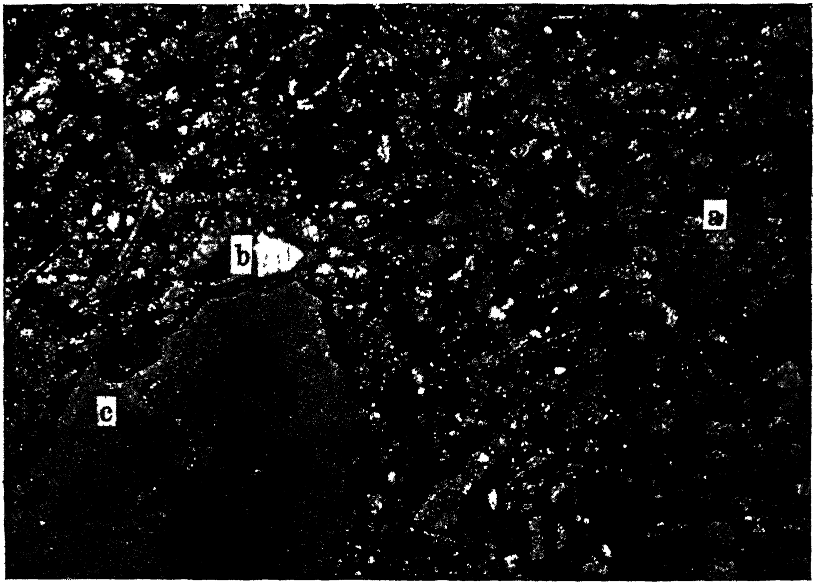


FIG. 6. Microphotograph of limestone, 219 B5d; slide 254; enlarged 22 diam. *a*, calcite; *b*, quartz; *c*, phosphatic? nodules.

more calcareous portions. Hematite (Fig. 7, Slide 257) is found in the more jaspery or laminated areas as irregular grains, aggregations, and spherules associated particularly with the green area which for the most part is of an indeterminable character. Veins of calcite are found cutting the nodule. As in the layer above, there are found in this one (Fig. 8, Slide 253), certain semi-isotropic nodular areas or pebbles which are partially chloritized. It is very possible that these nodular or pebbly areas are similar to the phosphatic nodules of 219 A 13 to be described later. These alter to carbonate locally. Among the organic remains are fragments of shells, hyolithes, trilobites, and sponge spicules, which in part show carbonate and chloritic replacement (Fig. 5, Slide 254, and Fig. 7, Slide 257).

219 A 1. Disconformably upon the above described nodular limestone there rests about 34 feet of a hard, fissile, green shale. About

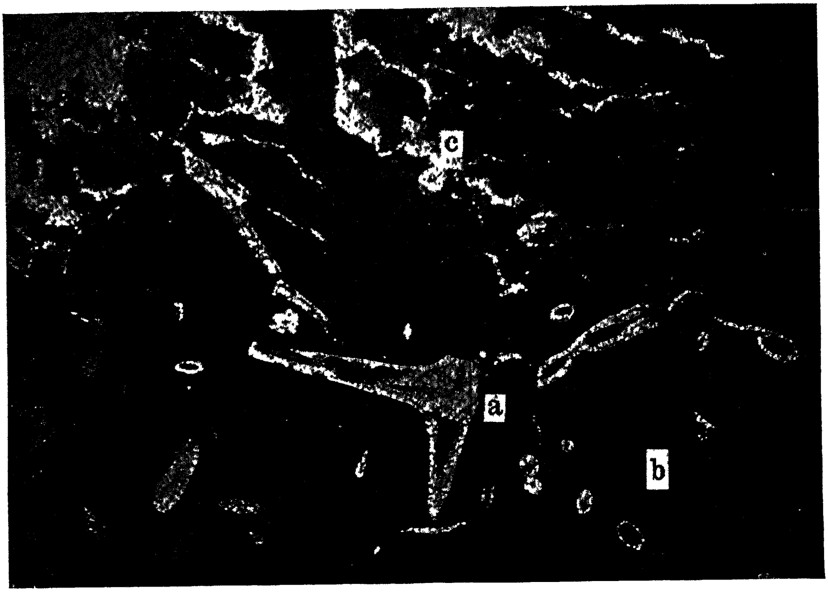


FIG. 7. Microphotograph of sponge spicules, 219 B6a; slide 257; enlarged 22 diam. a, sponge spicule; b, hematite; c, calcite.

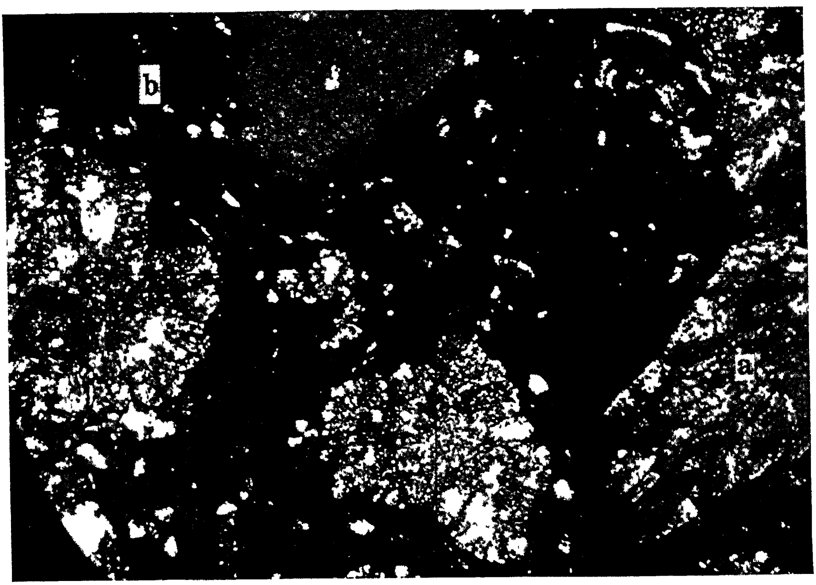


FIG. 8. Microphotograph of limestone, 219 B5d; slide 253; enlarged 22 diam. a, calcite; b, phosphatic? material.

5 feet above the limestone there are thin seams full of comminuted fragments of small *Lingulella,* and *Hyolithes* shells. The upper part of this shale is conspicuous because of the conchoidal fracture with which it breaks and the presence of local aggregations of small sub-spherical black nodules some of which show pinkish centers of some fine-grained minerals such as rhodochrosite or manganiferous calcite. MnO_2 occurs as small dots or as dendritic areas on the fracture planes. Microscopically, this is a chloritic micaceous shale containing sparingly, among the visible minerals, irregular grains of plagioclase, quartz, pyrite, magnetite and limonite in descending order of abundance.

219 A 2 is a nodular shale bed of .5 of a foot in thickness and forming the sloping surface over which the stream runs. This bed is noteworthy because of the Cryptozoon colonies showing on the surface (see Fig. 10).

219 A 2a, the lower portion of this bed, is a green shale containing frequent small subspherical nodules and disseminations of a pink carbonate which effervesces freely and is in all probability a manganiferous calcite similar to the pink nodules analyzed (see page 395).

219 A 2b is the Cryptozoon shale bed and contains roughly concentric or zonal structures measuring 1½ inches in diameter, irregular and sub-spherical nodules measuring 1 inch in diameter, and intercalated lenses of manganiferous calcite. These nodular and Cryptozoon structures weather brown. Scattered through the bed, particularly the shaly portions, are blades of barite.

Microscopic examination of this Cryptozoon bed brings out nothing which can be said to be of an organic structure. What structure there is may be characterized as broken veinous, concentric and laminated. The texture in great part is crystalline. The greater portion of one of the nodules consists of calcite and carbonate. Barite occurring as long blades is determined principally by the two cleavages, c and m, its birefringence greater than quartz and its biaxial + character. Chlorite either alone or in combination with carbonate is found replacing barite. Calcite or carbonate occur as irregular masses or as rudely formed or incipient spherules. Hematite occurs in the banded portions as more or less massive bands interlaminated with chlorite or as rudely formed spherules in the

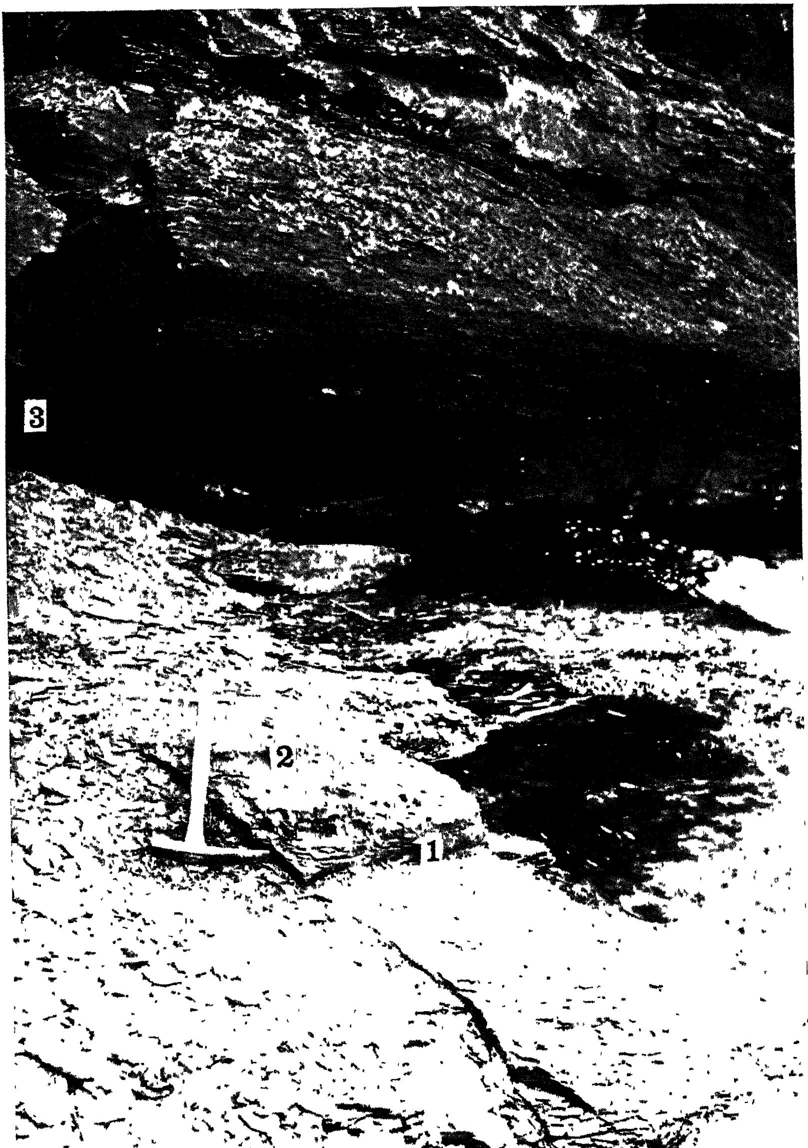


FIG. 9. Details of lower portion of manganese zone in Manuels brook.

Fig. 10. Photograph of upper surface of Cryptozoon bed, 219 A2, in left bank Manuels brook.

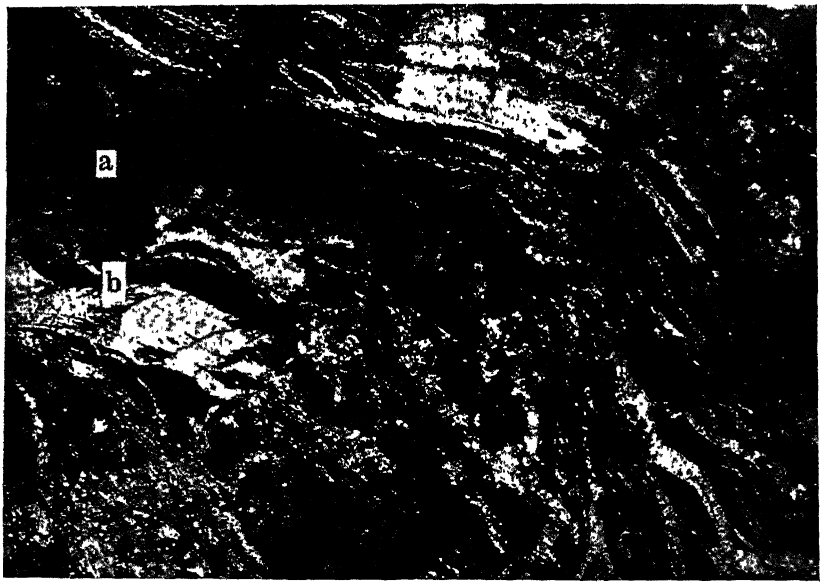


FIG. 11. Microphotograph of section of Cryptozoon nodule, 219 A2; slide 292; enlarged 22 diam. a, ferruginous band; b, calcite.

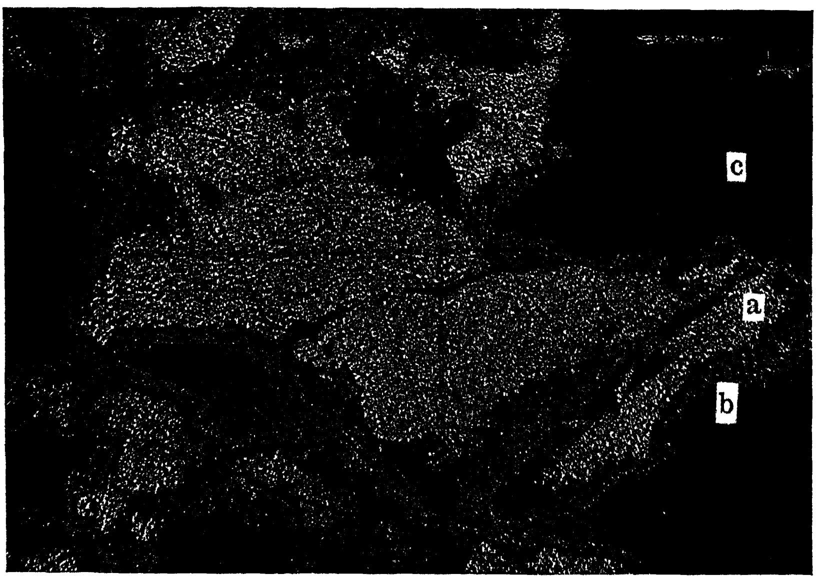


FIG. 12. Microphotograph of Cryptozoon nodules from 219 A2, showing barite being replaced by chlorite; slide 292; enlarged 22 diam. a, barite; b, chlorite; c, ferruginous and calcareous shale.

ground mass. These spherules measure as small as 9 microns in diameter but have an average diameter of between 30 and 40 microns (Fig. 11 and 12, Slide 292).

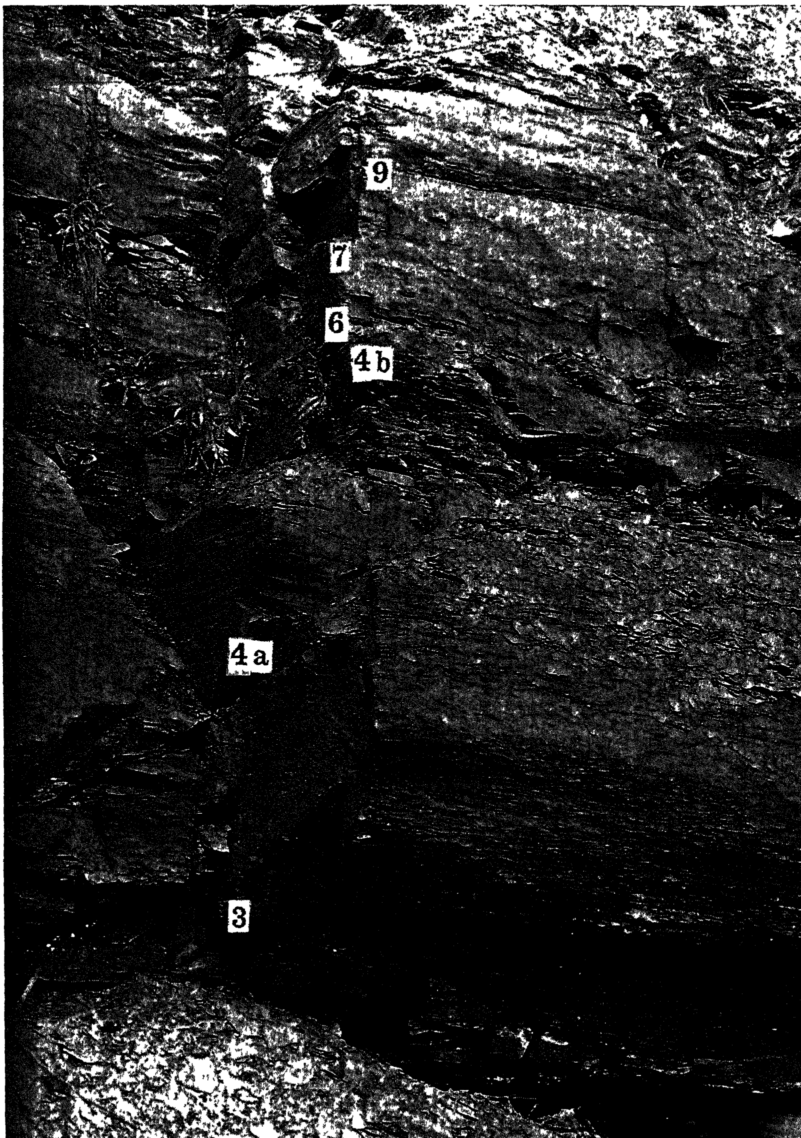


FIG. 13. Middle portion of manganese zone in Manuels brook. The numbers are those of the section.

The paragenesis of minerals within the nodules is as follows: Calcareous or carbonate material with probably synchronously formed hematite, barite veining, chloritization replacement, and finally calcite as vein or replacement material.

219 A 3 is a green shale bed, 3 feet in thickness, lying conformably above the Cryptozoon nodular bed. For the most part this bed consists of a hard fissile green shale which breaks with a conspicuous

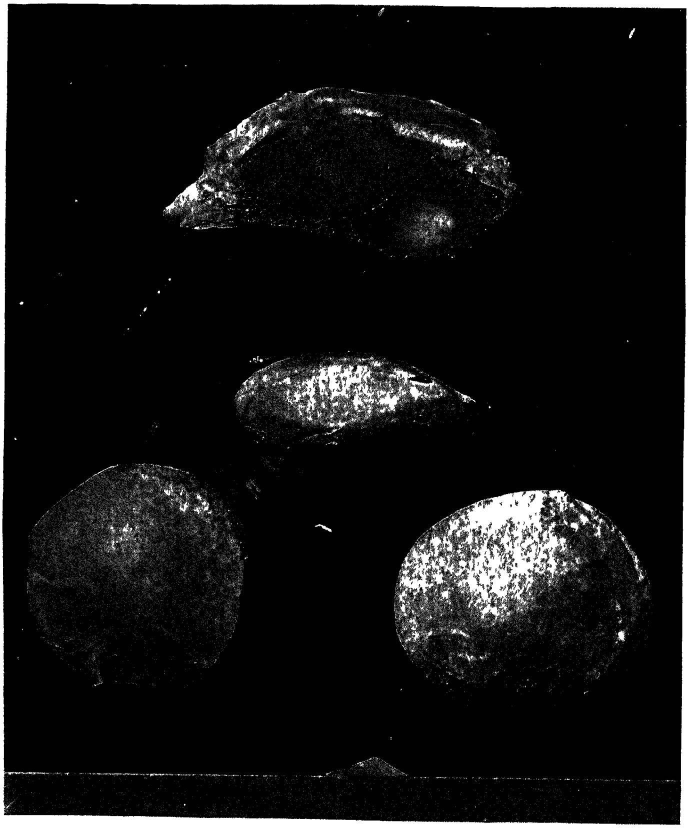


FIG. 14. Photograph of manganese carbonate nodules extracted from shale 219 A4, natural size. Top, side and sectional views.

conchoidal fracture. 3 inches above the Cryptozoon bed is a layer containing fragments of trilobites which according to Prof. G. van Ingen are probably to be identified as *Protolenus harveyi*. Barren

green shale overlies this fossiliferous layer and this in turn is followed by nodular green shale containing manganiferous calcite nodules, a description of which is given in connection with the following bed.

FIG. 15. Photograph, natural size of ground and polished horizontal section of shale containing manganese carbonate nodules from 219 A4.

219 A 4 is a conspicuous rhodochrosite and manganiferous calcite nodular bed and may be considered the base of the manganese zone at Manuels (Fig. 13). Structurally this is a nodular and oölitic bed, the former structure conspicuously observable macroscopically, and the latter, though not so well defined a structure, observable microscopically. The entire bed measures 5.1 feet in thickness and is divisible into two members, **a** and **b**. The lower member, 219 A 4**a** is a predominantly nodular reddish green shale while the upper division or **b** member is not so nodular.

The nodules of 219 **A** 4a are discoidal in shape and vary in diameter from 1/6 inch to 1 1/2 inch, with an average of about 1 inch and a thickness ranging from 1/8 inch to 1/2 inch. The longer diameters of the nodules lie in the plane of the bed. Where the nodules are very numerous or crowded they are found intergrown with or overlapping each other. Specimens ground and polished often show a lemniscate formed by two nodules (Figs. 14 and 15). In color they are for the most part green, but may have greenish, white, or pink central cores. Cross sections of the nodules reveal a distinct zonal arrangement with spherical central cores surrounded by concentric

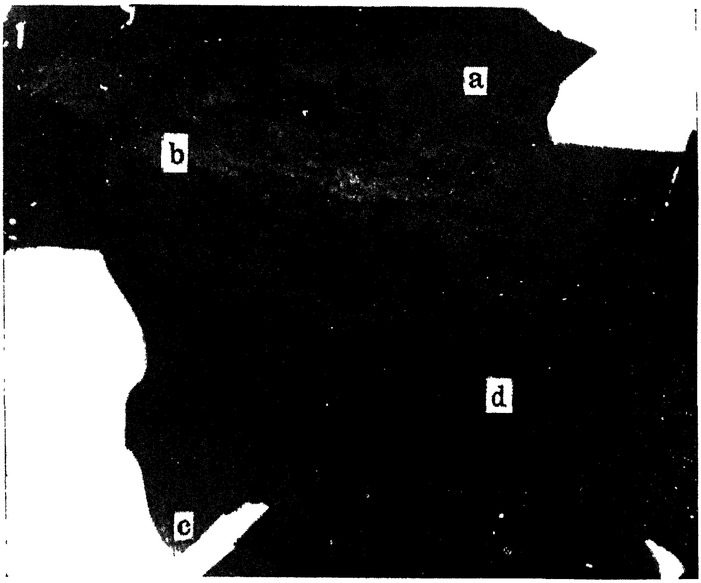


FIG. 16. Microphotograph of manganese carbonate nodule from 219 A4a; slide 288; enlarged 6 diam. a, carbonate of manganese, lime and magnesia; b, barite; c, barite replaced by chlorite; d, shale.

shells conforming to the shape of the nodule. The grain of the nodules is usually exceedingly fine, impalpable or crystalline. The pinkish cores are usually crystalline and respond to the HCl test quite readily, indicating some carbonate mineral. By analysis the green nodules are found to consist essentially of rhodochrosite (see Anal. *B*, page 395), while the pinkish crystalline mineral occupying

the centers of the nodules or occurring as intercalated lenses or nodules in the nodular bed is found to be essentially a maganiferous calcite (see Analysis *C*, page 395).

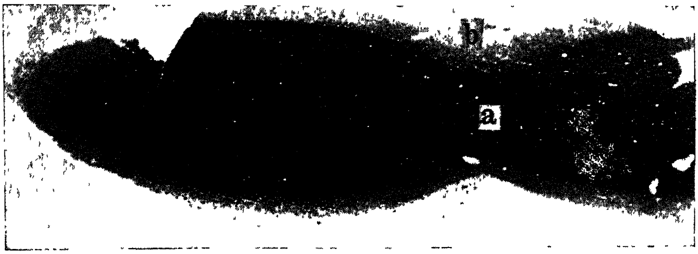


FIG. 17. Microphotograph of coalescing nodules from 219 A6c; slide 243; enlarged 4 diam. a, carbonate of manganese, etc.; b, oölitic shale.

Further macroscopical examination of the nodules shows the presence of barite blades within the central portions of the nodules or disseminated throughout the nodule or its shaly matrix. The characteristics which determined the barite are its c and m cleavage, its hardness of 2 and its diaphaneity. Its optical properties confirm it microscopically. Pyrite is found sometimes completely surrounding central cores as irregular and continuous grains. The surfaces of the nodules usually are covered with minute pink or reddish disseminated grains which upon microscopic examination are found to be hematitic spherules.

Thin sections of these nodules, on the whole, are not satisfactory for microscopical work because of the almost impalpable fineness of the grain. However some of the larger features may be of interest and importance. The structure is nodular and concentric and some of the concentric shells are oölitic. In all the thin sections of nodules the most conspicuous feature is the zonal arrangement of crystalline and indeterminable portions. The crystalline parts usually occupy the centers of the nodules while the impalpable or indeterminable areas are arranged around the centers (see Fig. 16, Slide 288). However some of the cores consist of indeterminable material. The zones are sometimes marked off from each other by more or less sharp contracts as brought out by a difference in shade of color or by an apparent difference in grain (Figs. 17, and 18).

The exterior zones merge imperceptibly into the shale, a fact which has some genetic significance.

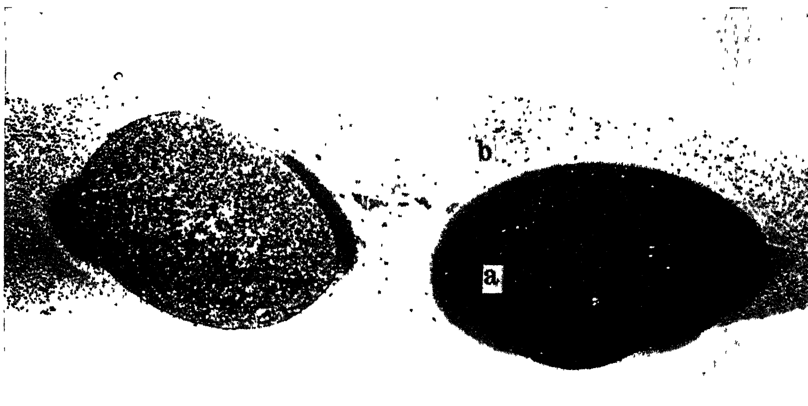


FIG. 18. Microphotograph of two manganese carbonate nodules from 219 A6c; slide 237; enlarged 8 diam.

An incipient oölitic structure with spherules of hematite is common to the outer zones of the nodule and shaly matrix. The spherules do not as a rule show any well-developed zonal structure nor are they of very regular form. They vary in diameter from 6 microns to 77 microns and have an average diameter of about 24 microns. Not infrequently the spherules consist of both carbonate and hematite, the former preserving a radiating structure and abounding in the more calcareous portions of the specimen, while the hematitic spherules are more common in the shaly parts.

Among the determinable minerals are calcite, which occurs as anhedral grains of variable dimensions in small crystalline areas, in veins, or as replacement material after organic remains such as sponge spicules, etc. Carbonate material for the most part specifically indeterminable makes up the greater part of the slide. Barite is found occupying the more central portions of the nodule in some sections. Quartz as irregular grains occurs only in sparing amounts. Pyrite is present as large and small irregular grains and masses.

The analyses of the green and pink nodules are as follows:

ANALYSIS *B*.

Green Nodules.

SiO_2	10.31
Fe_2O_3	7.35
Al_2O_3	3.68
MnO	31.76
CaO	10.46
MgO	1.80
$BaSO_4$	6.43
H_2O	2.85
CO_2	25.31
	99.96

ANALYSIS *B* 1.

Recalculation.

$MnCO_3$	39.56
MnO	7.30
$CaCO_3$	18.61
$MgCO_3$	3.79
SiO_2	5.94
$BaSO_4$	6.29
H_2O	1.51
Fe_2O_3	7.35
$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	9.17
	99.52

ANALYSIS *C*.

Pink Nodules.

SiO_2	5.14
Fe_2O_3	1.40
Al_2O_3	1.64
MnO	20.49
CaO	32.92
MgO	.01
H_2O	1.65
CO_2	36.77
	100.02

ANALYSIS *C* 1

Recalculation.

$CaCO_3$	58.05
$MnCO_3$	29.32
MnO	2.34
SiO_2	3.78
Fe_2O_3	1.40
H_2O	1.06
$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	4.07
	100.02

The pinkish crystalline mineral which exhibits a rhombohedral cleavage, has a hardness of about 3, effervesces freely with HCl acid, and, with the above composition, is essentially a manganiferous calcite. The excess MnO probably exists as a peroxide of manganese as indicated by the considerable amount of chlorine which was given off while the sample was being digested with HCl acid. As no thin sections were made of this specimen no petrographic confirmations can be made.

The upper subdivision of 219 A 4 (**219 A 4b**) is a greenish and reddish nodular shale bed measuring 2.9 feet in thickness and divisable into three roughly distinct portions. The lower part, **219 A 4b 1** is a greenish red shale overlaid by a reddish shale with occasional small nodules measuring about ¼ inch in diameter (Fig. 13, and 19).

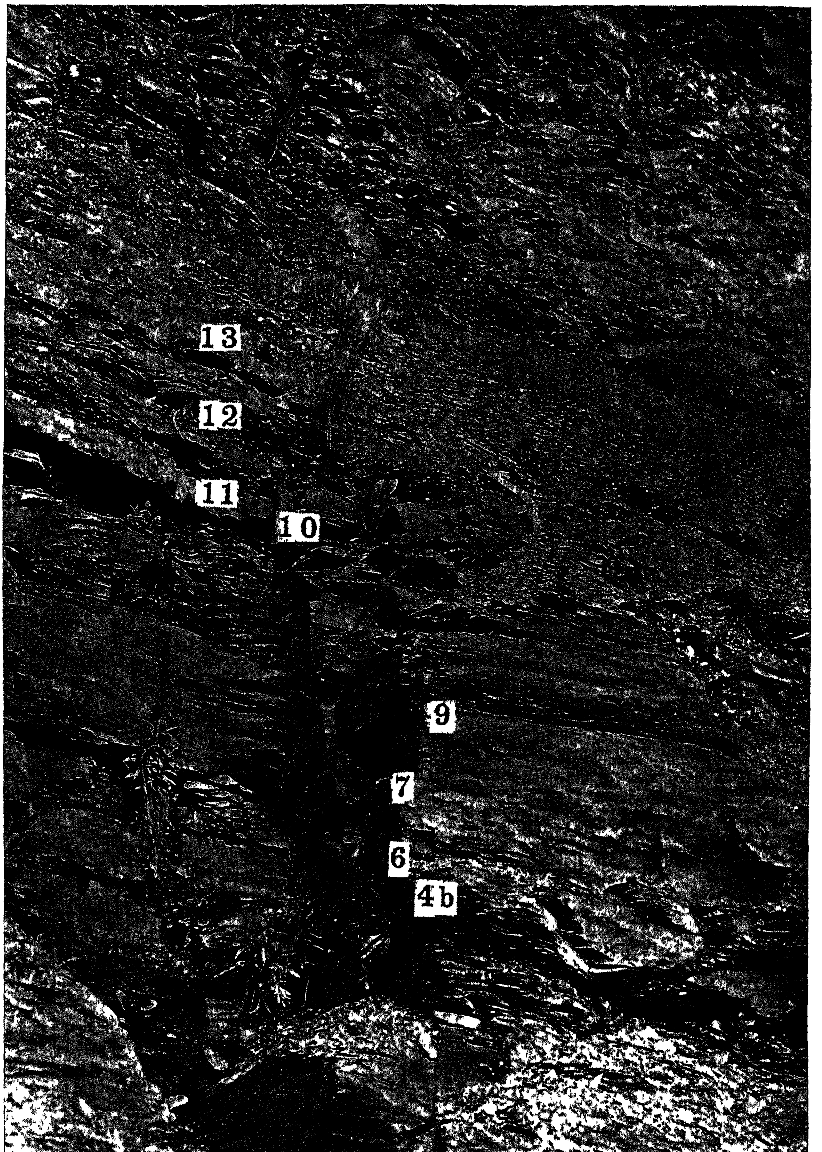


FIG. 19. Middle and upper portions of manganese zone in Manuels brook.

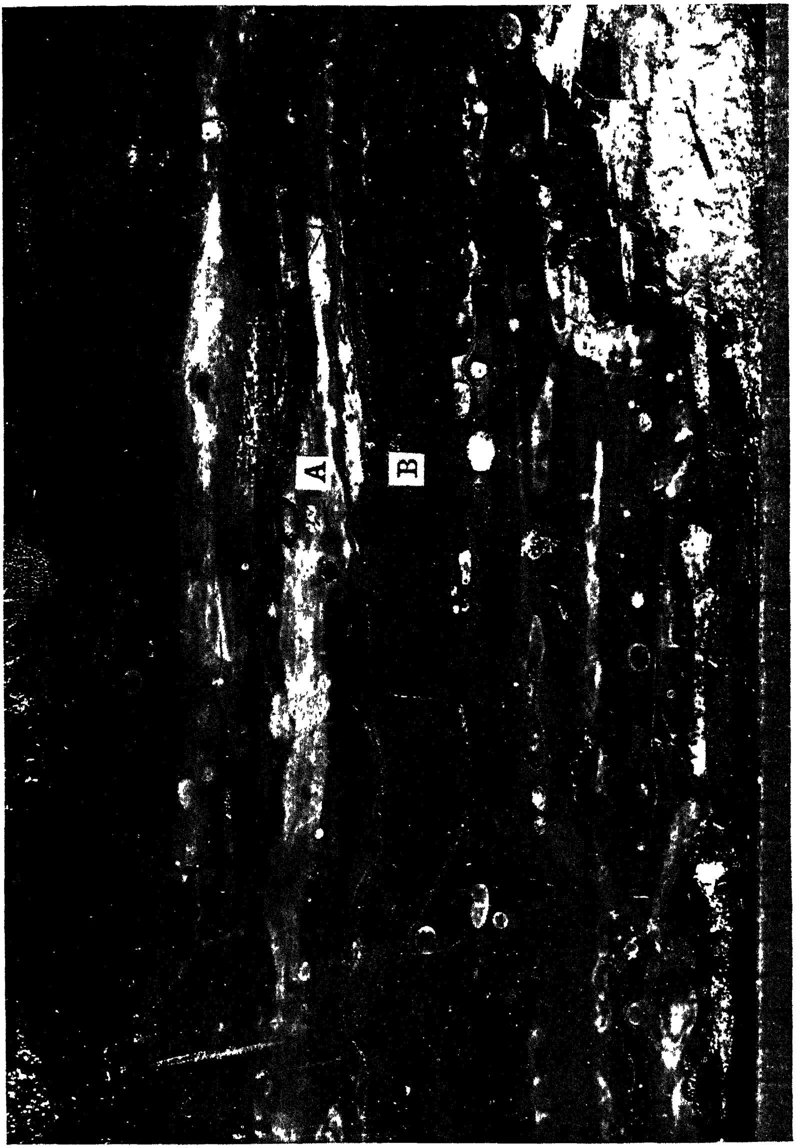


FIG. 20. Photograph of polished vertical section of banded manganese carbonate-oxide ore, 219 A7, slightly enlarged (1.8 diameters). a, green band; b, red band.

Under the microscope a thin section of this bed reveals hematite in the form of a pigment and as grains and ill-formed spherules, while local areas of carbonate are found. The upper member of this bed, **219 A 4b 3** is a red shale containing small subspherical and discoidal nodules quite similar to those described in detail above.

219 A 5 is a nodular ferruginous shale which is calcareous and manganiferous. The shaly structure and the manganese are brought out in a conspicuous way through weathering; the manganese by the black discoloration in evidence as one of the derived oxides. This bed has a thickness of .2 of a foot but thins and thickens, presenting a lenticular appearance. The nodules, or possibly pebbles, are subspherical in form, dark green in color, and of impalpable fineness of grain. They resemble those already described in connection with the

FIG. 21. Photograph of polished vertical section of banded manganese carbonate-oxide ore from 219 A7, natural size. a, green band; b, red band; c, barite.

219 B 5 limestone and those about to be described in beds 219 A 11 and 219 A 13, and are probably phosphatic pebbles in compostion. The minerals in evidence in this bed are hematite, calcite, and barite. This bed is undoubtedly a manganiferous bed as shown by the oxi-

FIG. 22. Photograph of vertical polished section of banded manganese carbonate-oxide ore from 219 A7, natural size. a, red band; b, brown band.

dized weathering products. The bed as a whole resembles 219 A 11 which to all appearances is suggestive of mineralized reworked material.

219 A 6 is somewhat fine-grained and gritty red shale, measuring 0.4 to 0.5 of a foot in thickness.

219 A 7 is the main manganese-bearing bed, measuring .7 of a foot in thickness. This bed is of more than usual interest in that the manganese occurs as primary carbonates and oxides in the form of thin jasper-like bands of green and light chocolate brown color, and as lenticles, and nodules. Interlaminated with the jaspery bands are reddish bands with manganese essentially in the form of an oxide and a carbonate (Fig. 20, 21, and 22). This bed has been divided into three layers, **a**, **b**, and **c**. The lowermost or **a** subdivision is the reddish band which is essentially a manganiferous shale. It is nodu-

lar with nodules, lenticles, and bands of the green jaspery carbonate and oxide of manganese. Wherever the jaspery minerals occur in the red band, whether as nodules, lenticles, continuous or non-continuous bands, they present or suggest concretionary characteristics. The red bands are locally pyritiferous and barytic. Red shale occupies the greater portion of the bed.

Microscopic examination of this red band brings out very little, other than that it is distinctly hematitic with the hematite occurring as a pigment or as irregular accumulations (Fig. 23, Slide 276).

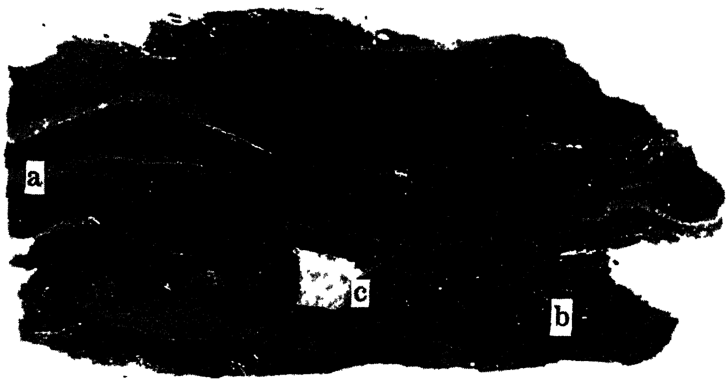


FIG. 23. Microphotograph of banded manganese ore with barite, from 219 A7; slide 276; enlarged 9.5 diam. a, red band; b, green band; c, barite.

The chemical analysis of this band is as follows:

ANALYSIS *E*.

Red Bands.

SiO_2	27.61
Fe_2O_3	4.25
FeO	1.69
Al_2O_3	6.96
MnO	26.05
CaO	9.94
MgO	3.49
P_2O_5	4.71
H_2O	4.73
CO_2	10.57
	100.00

ANALYSIS *E* I.

Recalculation.

MnO	19.71
$MnCO_3$	10.23
$MgCO_3$	7.25
$CaCO_3$	7.50
$Ca_3(PO_4)_2$	10.31
SiO_2	19.44
H_2O	1.87
$2H_2O \cdot Al_2O_3 \cdot 2SiO_2 + FeO$	19.01
Fe_2O_3	4.25
	99.57

Of most interest in connection with this red shaly band are the jaspery bands of green and brown carbonate and oxide of manganese. Where in bands, they vary from ⅛ inch to 1 inch + in thickness and may be continuous. The contact with the red band may be very even or very undulatory. This wavy character may be present whether the band thickens or thins or is of the same thickness throughout. The brown and green jaspery bands may contain thin laminæ or nodules of other colors.

The green material is characterized by its chalcedonic and somewhat waxy luster, its translucency on thin edges, its hardness of 5 to 6, its specific gravity of about 3.13 (that of the green nodule) and its slight response to HCl.

The chemical analysis of this material is as follows:

Analysis *A*. Green Band.		Analysis *A* 1. Recalculation.	
SiO_2	7.24	$MnCO_3$	44.39
Fe_2O_3	3.36	MnO_2	8.08
FeO	3.21	$CaCO_3$	20.11
Al_2O_3	6.11	$MgCO_3$	4.21
MnO	35.53	FeO	3.36
CaO	11.30	H_2O	.86
MgO	2.30	$2H_2O \cdot Al_2O_3 \cdot 2SiO_2 + FeO$	18.24
H_2O	2.98		99.25
CO_2	28.06		
	100.09		

The green band so very similar chemically to the green nodule already described in connection with the nodular bed lower down in the series, is in great part a rhodochrosite in composition but has in combination, in descending order of abundance, considerable amounts of calcareous, argillaceous and ferruginous material. Manganese not combined with CO_2 probably exists as some oxide, probably a peroxide, as considerable chlorine was given off by the sample when first treated with concentrated HCl. Other features hardly need any explanation.

Thin sections of this band are very unsatisfactory in that, because of the impalpable fineness of the grain, little can be seen outside of structural features and certain opaque minerals, chiefly hematite.

The brown band differs in chemical composition, in color, and in specific gravity. The color is a light or dark chocolate brown. The specific gravity is 3.32. The chemical composition differs mainly in the higher percentage of manganese, as shown in the following analysis:

ANALYSIS *D*.

Brown Band.

SiO_2	10.23
Fe_2O_3	1.32
FeO	.89
Al_2O_3	4.84
MnO	49.25
CaO	8.11
MgO	3.02
H_2O	1.31
CO_2	21 83
	100.80

ANALYSIS *D* 1.

Recalculation.

MnO	28.93
$MnCO_3$	32.89
$CaCO_3$	14.01
$MgCo_3$	5.90
$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	11.08
SiO_2	5.40
Fe_2O_3	1.27
	99.48

Members **b** and **c** of bed **219 A 7** differ from the subdivision just described in the greater abundance of jaspery bands in comparison with the red shaly band and they show greater continuity on the whole.

Member **d** consists of green and brown jaspery bands all more or less nodular and interlaminated with the red manganiferous shale. Barite as segregations, disseminated blades, and veins occur infrequently. In the weathered portions of the section this bed is found altering on its more exposed structural planes to the secondary oxides of manganese such as psilomelane, etc.

219 A 8 is a purplish manganiferous nodular shale measuring 0.3 of a foot in thickness. It contains lenticles and discoidal nodules of the green jaspery manganese carbonate (Fig. 24, Slide 284). The noticeable microscopic features of a thin section of this rock are its nodular, oölitic and shaly structures. The spherules, though rudely formed, are of either hematite or a carbonate, the former more closely associated with the green jaspery structures, and the latter with the red shale.

219 A 9 is a manganiferous bed structurally, mineralogically, and, presumably, chemically, analogous to 219 A 7, and measuring .5 of a

foot in thickness. Green discoidal nodules of manganese carbonate and the green, brown and red manganiferous bands similar to those of 219 A 4 are a conspicuous feature of the bed. A thin section from one of the nodules of this bed collected during the summer of 1912 shows, aside from the nodular form, conspicuous zonal and

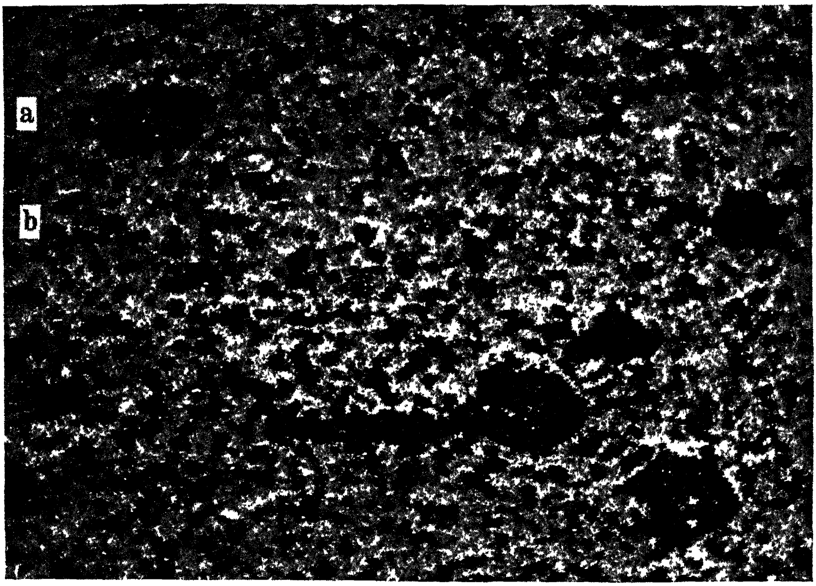


FIG. 24. Microphotograph of red shale from 219 A8; slide 284; enlarged 38 diam. a, hematite aggregation; b, spherules of hematite.

oölitic structures. For the most part the grain is impalpable, but that of the core is more or less crystalline. There are five pronounced parts consisting of a crystalline innermost core, No. 1, which in a great part is composed of carbonate, presumably that of calcium and manganese though nothing of a definite confirmatory nature could be observed, and 4 successive enveloping shells differentiated from each other by either the presence or absence of hematite, the shade or intensity of color or by fineness of grain. The oölitic character of zones 3 and 5 with spherules consisting in great part of hematite and measuring as small as 12 microns and as large as 90 is very noticeable. Layers 2 and 4 in a great degree consist of

indeterminate material (Fig. 25, Slide 244). Anisotropic minerals in this section are not common but those most noticeable are calcite,

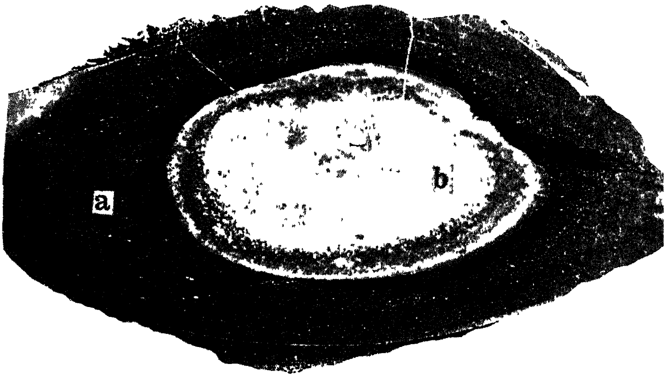


FIG. 25. Microphotograph of nodule, from 210 A7; slide 244; enlarged 4.0 diam. **a**, outer zone of manganese carbonate; **b**, core of crystalline manganese carbonate.

barite, and chlorite, the latter being usually associated with the barite.

219 A 10 consists of 3.5 feet of alternate layers of purple and green shale which contain thin nodules and lenticles of jaspery manganese carbonate, some of which measure 1.3 feet in length and 0.1 feet in thickness. The lowermost subdivision of this bed, **210 A 10a,** is a dark reddish-green heavy nodular and oölitic shale with nodules very similar to those described above. Disseminated minute reddish mineral particles suggesting hematite spherules are found rimming the nodules in some cases. Barite occurs occasionally. Subdivision **b** of this bed is composed of 0.2 of a foot of green and red lenticular manganiferous seams with green jaspery nodules, similar to those in the lower beds, interlaminated with a hematic oölitic shale. Subdivision **c,** measuring 0.5 of a foot in thickness, is a dark gray oölitic and slightly nodular shale with green jaspery seams. Barite blades occur with nodular accumulations of manganiferous calcite. Microscopically this layer is essentially a hematitic oölitic shale with the individual spherules measuring from 15 to 23 microns in diameter while larger aggregations of spherules measure from 0.253 mm. to 0.387 mm. in diameter. The spherules consisting of hematite and car-

bonate are found in a groundmass the character and composition of which is for the most part indeterminable. Occasional pyrite grains are found (Fig. 26, Slide 280).

219 A 10d, the upper subdivision, consists of 0.3 of a foot of nodular and oölitic dark gray shale with thin jaspery manganese carbonate laminations.

Subdivision **e** is a dark green nodular and oölitic shale, 0.8 of a foot in thickness and not very different from the layer **d** just de-

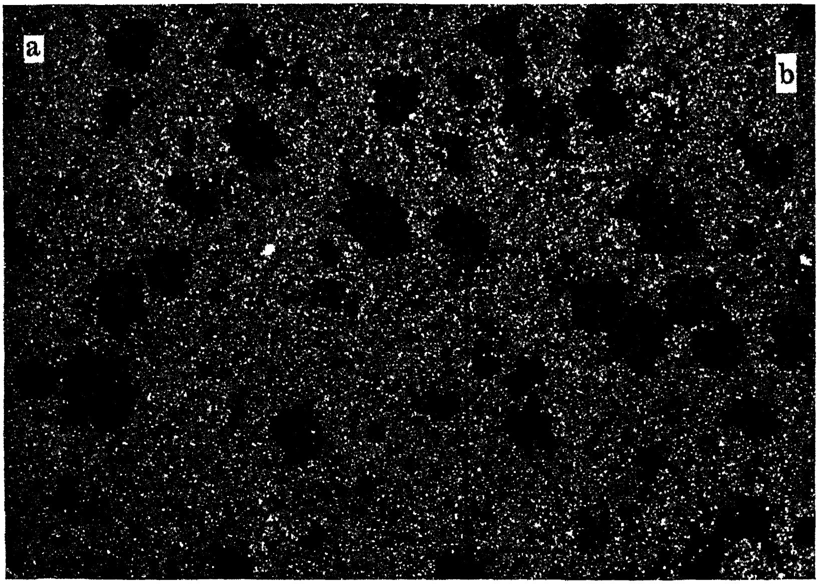


FIG. 26. Microphotograph of oölitic manganiferous shale from 219 A10c; slide 280; enlarged 22 diam. a, hematite spherules; b, shale with disseminated hematite.

scribed, and f—is a coarse nodular seam, 0.8 of a foot in thickness, in a dark green shale, comprising the uppermost portion of this bed.

219 A 11 is a heavy tough reddish band, 0.5 of a foot in thickness and lithologically very different from the immediately overlying and underlying beds. For the most part, the structure is both somewhat nodular and oölitic. The general fragmentary nature of the fossils and of certain nodular or pebbly forms leads one to think

that this layer consists in some degree of reworked material. The surface of this bed shows ripple marks. The predominant constituents which a macroscopic examination affords are calcite, barite, argillaceous material, limonite, manganese oxide, and pyrite. Outside of the nodular, oölitic, and fragmentary character of the layer,

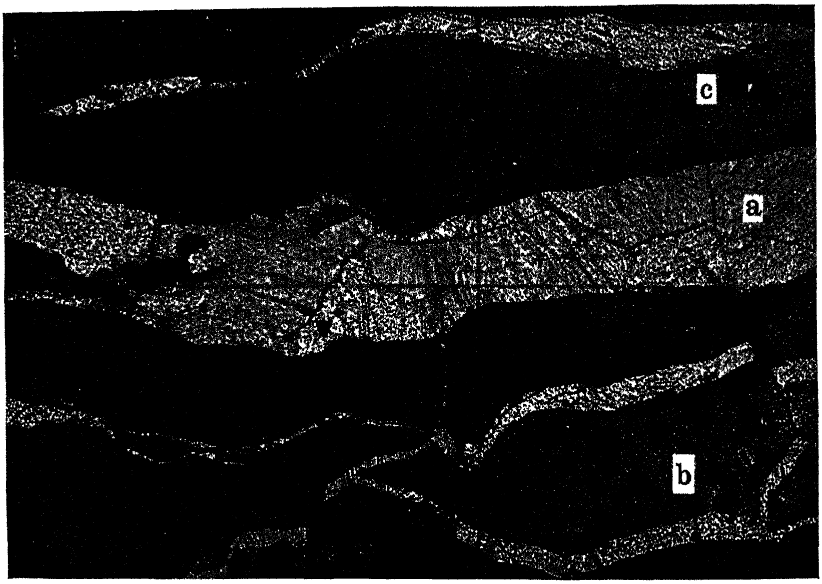


FIG. 27. Microphotograph of manganiferous red shale from 219 A11; slide 277; enlarged 22 diam. a, calcite vein; b, hematite spherule.

very little additional information concerning this peculiar rock could be gained microscopically (Fig. 27, Slide 277). The spherules are of two kinds, hematite and carbonate, and they average about 48 microns in diameter. Non-ferruginous portions of the slide show a groundmass of such fine-grained green material that very little could be made of it. *Hyolithes,* sponge spicules, and shell fragments partially or entirely replaced by calcite are a noticeable feature. Barite as scattered blades partially replaced by chlorite and pyrite, hematite as the chief constituent of the spherules, and carbonate are the most abundant of the determinable constituents of the slide (Fig. 28, Slide 278).

The chemical analysis of this rock is as follows:

ANALYSIS *F*.

219 A 11.

SiO_2	18.42
Fe_2O_3	6.33
Al_2O_3	7.95
MnO	21.44
CaO	14.46
MgO	5.01
P_2O_5	3.46
H_2O	2.58
CO_2	21.20
	100.85

ANALYSIS *F* 1.

Recalculation.

MnO	9.36
$MnCO_3$	19.22
$CaCO_3$	18 61
$MgCO_3$	10.54
$Ca_3(PO_4)_2$	7.50
Fe_2O_3	6.22
SiO_2	9.18
$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	19.61
	100.24

This bed is essentially a manganiferous argillaceous dolomite with considerable percentages of barite, hematite, and phosphate. It would seem quite reasonable to suppose that the phosphate $Ca_3(PO_4)_2$ exists in the nodular portion as we have found to be the case in the nodules of 219 A 13 to be described later.

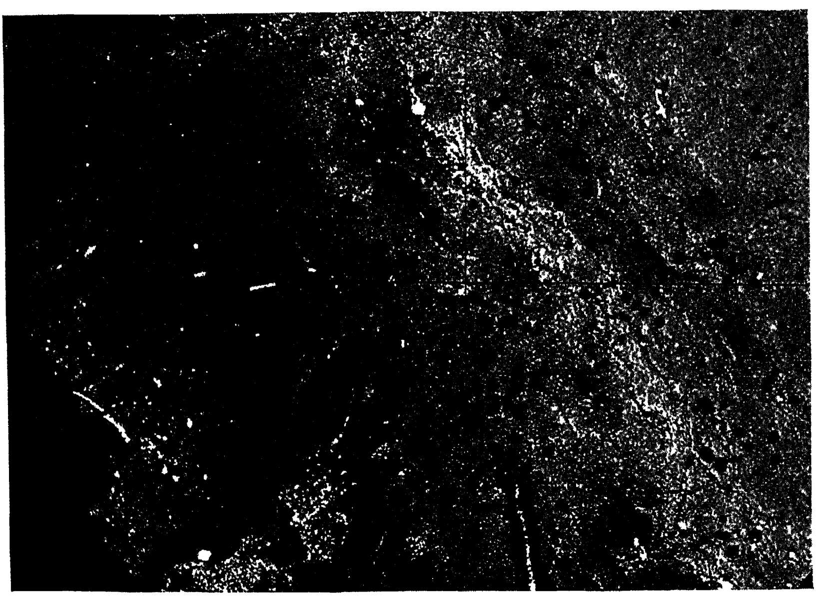


FIG. 28. Microphotograph of red manganiferous shale from 219 A11; slide 278; enlarged 22 diam.; showing hematite spherules in a groundmass of manganese carbonate.

219 A 12 is a fissile green shale measuring 1.4 feet in thickness with conspicuous black nodules which on weathering become white. Because of the similarity in form and color with those of 219 B 5, A 5, A 11, and those to be described from the bed immediately above this one, the suggestion is made here that these nodules also may be phosphatic.

219 A 13 is a phosphatic nodular manganiferous calcareous shale bed, 1 foot thick, with the nodules common in both bottom and top portions of the bed (Fig. 29). The nodules because of their white

FIG. 29. Photograph of a polished vertical section of a phosphatic nodular shale seam, 219 A13; natural size. a, phosphatic nodule; b, shale with trilobite fragments.

weathering and subspherical to elongated form resemble those of 219 A 12, A 11, A 5, and B 5. In chemical composition the nodules of this bed resemble those from the Cambrian of southern New Bruns-

wick described by W. D. Matthew (15). The chemical analyses of the Manuels brook and the New Brunswick phosphate nodules are as follows:

ANALYSIS *H*.

Manuels Brook, N. F.		*Hanford Brook, N. B.*	
SiO_2	25.20	SiO_2	24.74
Al_2O_3	7.67	Al_2O_3	11.85
Fe_2O_3	10.13	Fe_2O_3	11.44
CaO	23.50	CaO	22.35
MgO	4.78	KO	0.59
P_2O_5	17.68	MgO	2.29
H_2O	2.71	NaO	1.41
CO_2	2.23	P_2O_5	14.99
	93.90	H_2O	3.43
			3.44
		CO_2	3.53
			100.06

The similarity between the percentages of SiO_2, Fe_2O_3, CaO and P_2O_5 of the two analyses is at once very noticeable and at the same time very suggestive. It is hoped that at some future time, work of a correlative nature may be taken up in connection with these interesting and genetically problematical nodules. Among the macroscopically observable minerals in the fresh and altered rock are pyrite, hematite, limonite, wad or psilomelane, and vivianite in an argillaceous dolomitic groundmass. *Hyolithes* fragments are in abundance.

As no apparent manganese was observable in the considerable thickness of overlying green shales, 219 A 13 was considered to be the top of the manganese zone at Manuels Brook. According to Prof. van Ingen the *Paradoxides* fauna begins in these shales which immediately overlie the manganese zone.

TOPSAIL.—The manganese at Topsail some 4 miles east of Manuels (see Figs. 1 and 30) occurs interbedded in steep northerly dipping (50° to 78°) lower Cambrian strata consisting of shales, limestones and sandstones. The manganese is found in several beds of which only one measuring 1.4 feet in thickness seems to be of sufficient importance to have warranted prospecting, as shown by

some open cutting. This is a carbonate-oxide ore of manganese of brown color and vitreous luster.

Not only does the character and structure of the manganese at Topsail differ from that of Manuels but the section shows some

FIG. 30 Photograph of the open cut with the manganese prospect tunnel at Topsail; Loc. 219 E.

lithological variations. Moreover the rocks of the section are very much disturbed with the rapid changes in the dip of the beds. The structural changes in these beds are no doubt due to the great fault, the plane of which passes about 300 feet east from the manganese zone with a strike of N. 13 E. and a vertical dip. The fault plane lies between the Huronian and the lower Cambrian, and the beds immediately adjacent are considerably disturbed and so to a lesser extent are those farther away.

That a better idea may be obtained as to the relationship of the manganese, the following general and local stratigraphic sections with descriptions are given. The generalized section as worked out by Prof. van Ingen and Mr. A. O. Hayes during the summer of 1912 is as follows:

Loc. Number.		Ft.
210 E 10	Brown shales with manganese at base	Open cut
9	Brown shales with limestone at base.	
8	Heavy limestone.	
7	Shaly limestone	6.0
6	Brown sandstone with limestone nodules	3.0
5	Fine and coarse sandstone with small limestone nodules	6.0
4	Much sheared brown shale with limestone nodules and manganese at base	4.0
3	Mouth of tunnel and rotten zone	15.0
2	Coarse sandstone	6.0
1	Shear zone	0.3 to 0.5
0	Pre-Cambrian	25.0

It is quite apparent from a study of the above section that the lower Cambrian at Topsail is in many respects similar to that of Manuels. The absence of a basal conglomerate and the presence of sandstone are the most striking features of the associated beds. During the summer of 1913 a more detailed study of the manganese zone of 210 E 10 of the generalized section was made and the following subdivisions were made:

Loc. Number		Ft
219 E 7	Green shale, badly broken.	
6	Banded, concentric and nodular shale	1.0
5	Green shale, badly sheared	0.5
4	Manganese oxide-carbonate ore	1.4
3	Broken nodular green shale with manganese stain	0.7
2	Calcareous manganiferous shale	0.3
1	Hard nodular olive green shale, badly weathered and sheared, with manganese stain.	

Of this series two beds, 219 E 4 and 6, are worthy of more detailed description.

219 E 4 is an oxide-carbonate ore of manganese of 1.4 ft. in thickness. It is irregularly banded and nodular, of chocolate-brown color, somewhat vitreous in appearance and argillaceous, with a hardness of 5 to 6 and specific gravity of 3.26. Disseminated

through the ore are irregular small areas of a pink carbonate resembling rhodochrosite in physical characteristics, and barite. The ore is incrusted with psilomelane as an oxidation product. Microscopic examination brings out a coarsely banded and nodular structure with a groundmass of indeterminate material which is for the most part homogeneous to all appearances and of brown color.

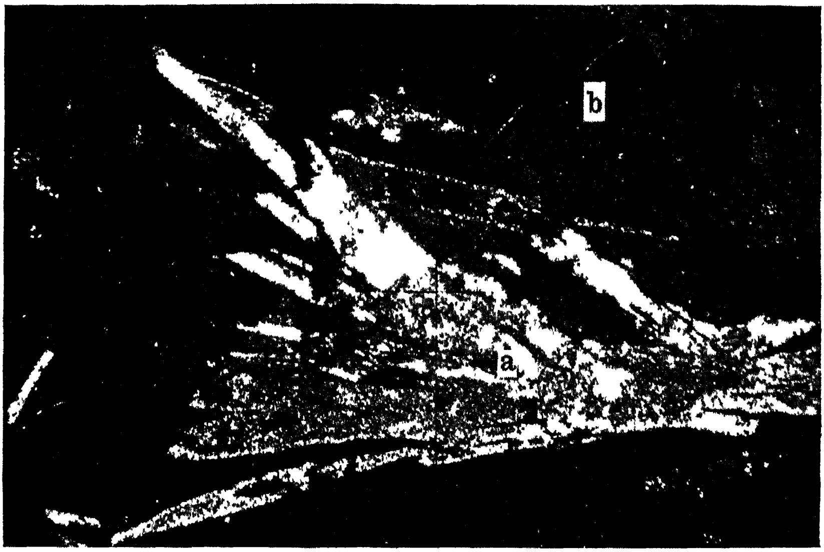


FIG. 31. Microphotograph of barite sheaf in manganese oxide-carbonate ore from 219 E4; slide 269; enlarged 22 diam. a, barite sheaf; b, manganese oxide-carbonate ore.

The color of this ore is due to the brown and black oxides of manganese and iron. Conspicuous among the anisotropic minerals are barite which occurs as blades or bundles of blades generally replaced by chlorite, and calcite, all very much discolored by the manganiferous and ferruginous oxides. Minute veins of discolored calcite are present (see Fig. 31, Slide 269).

The chemical analysis of the ore and its recalculation are as follows:

ANALYSIS I.

219 E 4

SiO_2	18.04
Fe_2O_3	4.82
Al_2O_3	6.58
MnO	41.26
CaO	2.24
MgO	2.39
$BaSO_4$	5.40
CO_2	8.34
H_2O	7.98
	97.05

ANALYSIS I I.

Recalculation.

MnO_2	34.25
$MnCO_3$	11.27
$CaCO_3$	4.00
$MgCO_3$	4.97
SiO_2	10.32
$BaSO_4$	5.40
Fe_2O_3	4.82
$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	16.30
H_2O	5.41
	96.74

This is essentially a hydrous oxide of manganese with considerable amounts of argillaceous material, rhodochrosite, silicious matter, dolomite, barite and hematite in descending order of abundance.

219 E 6, not a manganese ore bed, though manganiferous, is of interest mineralogically and petrographically. In structure it is concretionary and banded, nodular and microscopically oölitic. It is essentially a calcareous, ferruginous and manganiferous nodular and banded shale (see Fig. 32). Under the microscope the greater part of the groundmass, isotropic under crossed nicols, is of indeterminable composition simulating phosphatic material. Of the anisotropic minerals, calcite is most frequent and occurs with other carbonate material in bands which show an oölitic structure. The individual spherules, subspherical to elliptical in form show either concentric or radiated structure, the latter showing an interference cross with crossed nicols (Fig. 33, Slide 272). Calcite frequently has the curved twinning planes indicative of strain. Barite occurs in narrow veins or bands, as disseminated blades, or as sheath-like blades or aggregations, usually being replaced to a greater or less extent by chlorite and in a few instances by pyrite (Fig. 34, Slide 272). The spherules consist of hematitic pigment, carbonate and chlorite. Because of the frequent association of chlorite with barite one is led to suspect that possibly the chlorite spherules were originally of barite which has since been replaced by the chlorite. Other spherules made up in great part of hematite, sometimes show-

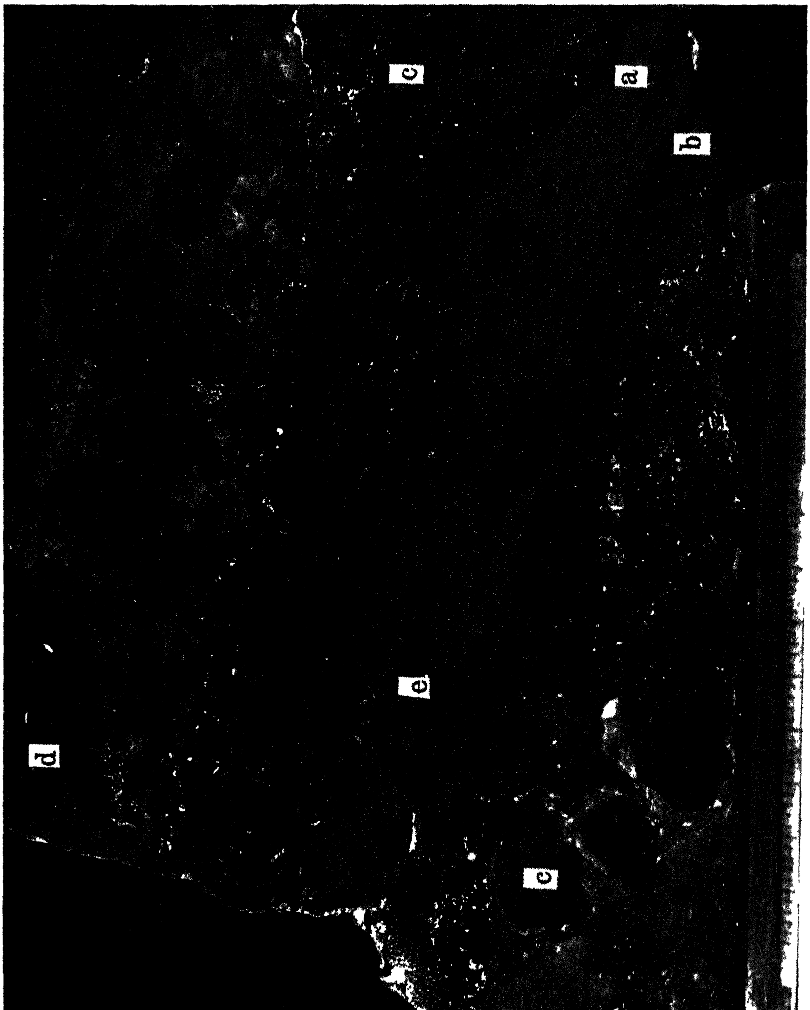


FIG. 32. Photograph of polished vertical section of banded and nodular shale from 219 E6; natural size. *a*, green shale; *b*, hematite nodule in hematite band; *c*, ferromanganese concretion; *d*, phosphatic nodule.

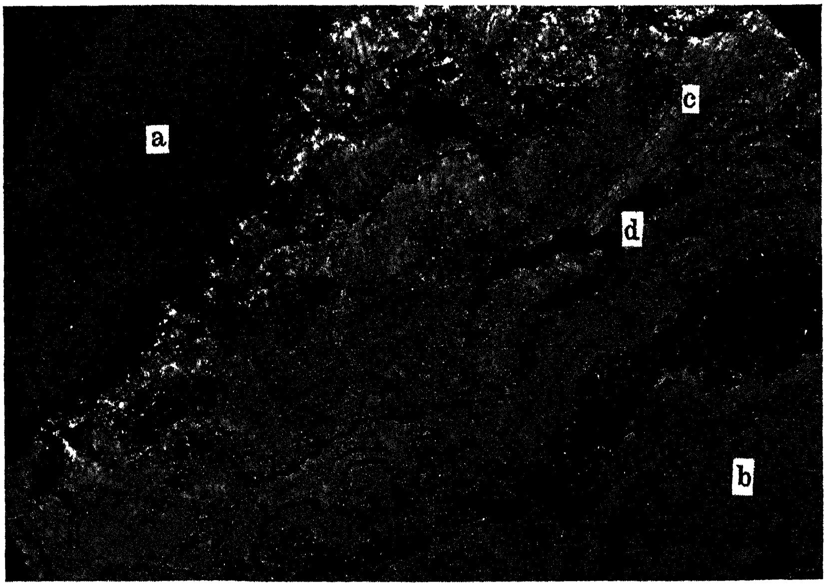


FIG. 33. Microphotograph of banded and nodular shale from 219 E6; slide 272; enlarged 38 diam. a, oölitic hematite shale; b, carbonate calcite band; c, barite; d, pyrite.

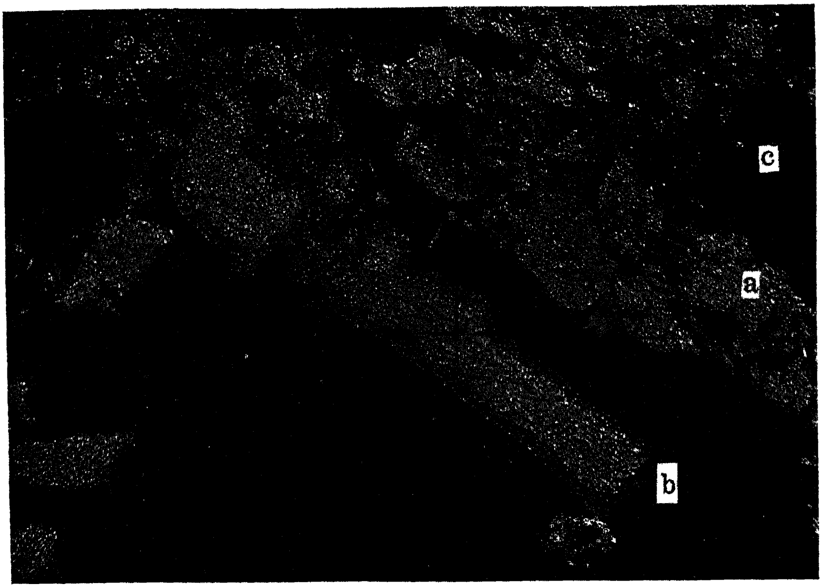


FIG. 34. Microphotograph of barite with chlorite replacement from 219 E6; slide 272; enlarged 22 diam. a, barite; b, chlorite replacing barite; c, phosphatic? material.

ing carbonate centers, are found most frequently in the jaspery bands. The spherules vary in size from 12 to 120 microns but have average diameter of about 94 microns.

The chemical analysis of this bed, with its recalculation, is as follows:

219 E 6.		*Recalculation.*	
SiO_2	18.24	$MnCO_3$	16.79
Fe_2O_3	10.01	$CaCO_3$	20.91
Al_2O_3	14.52	$MgCO_3$	10.57
MnO	10.42	$FeCO_3$	4.52
CaO	13.74	Fe_2O_3	5.49
MgO	4.94	$Ca_3(PO_4)_2$	3.75
P_2O_5	1.71	SiO_2	1.20
CO_2	24.01	$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	36.38
H_2O	2.07		99.61

From the above analysis, this rock is essentially a dolomitic manganiferous ferruginous shale with considerable amounts of $Ca_3(PO_4)_2$. Among the microscopically observable minerals in the above recalculation are calcite, hematite, quartz. The nodular portions, usually isotropic and of exceedingly fine grain, are probably

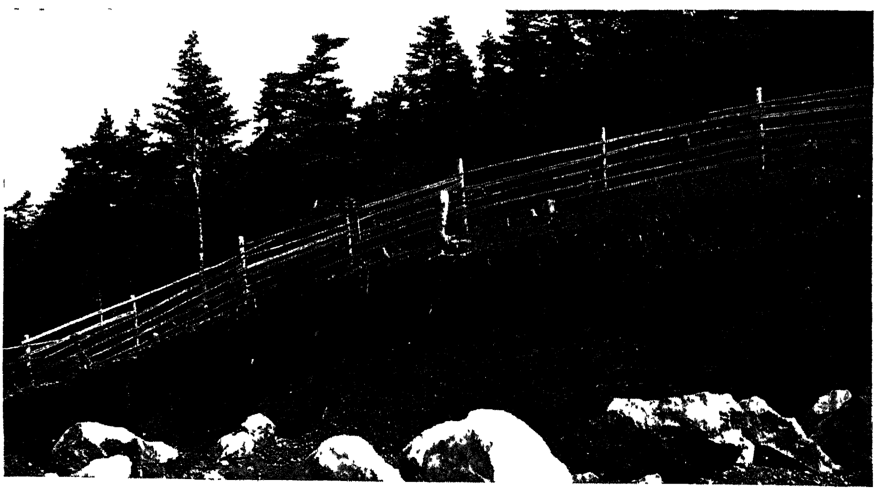


FIG. 35. Photograph of manganese prospect along the Kelligrews highway just south of Long Pond; Loc. 219 F.

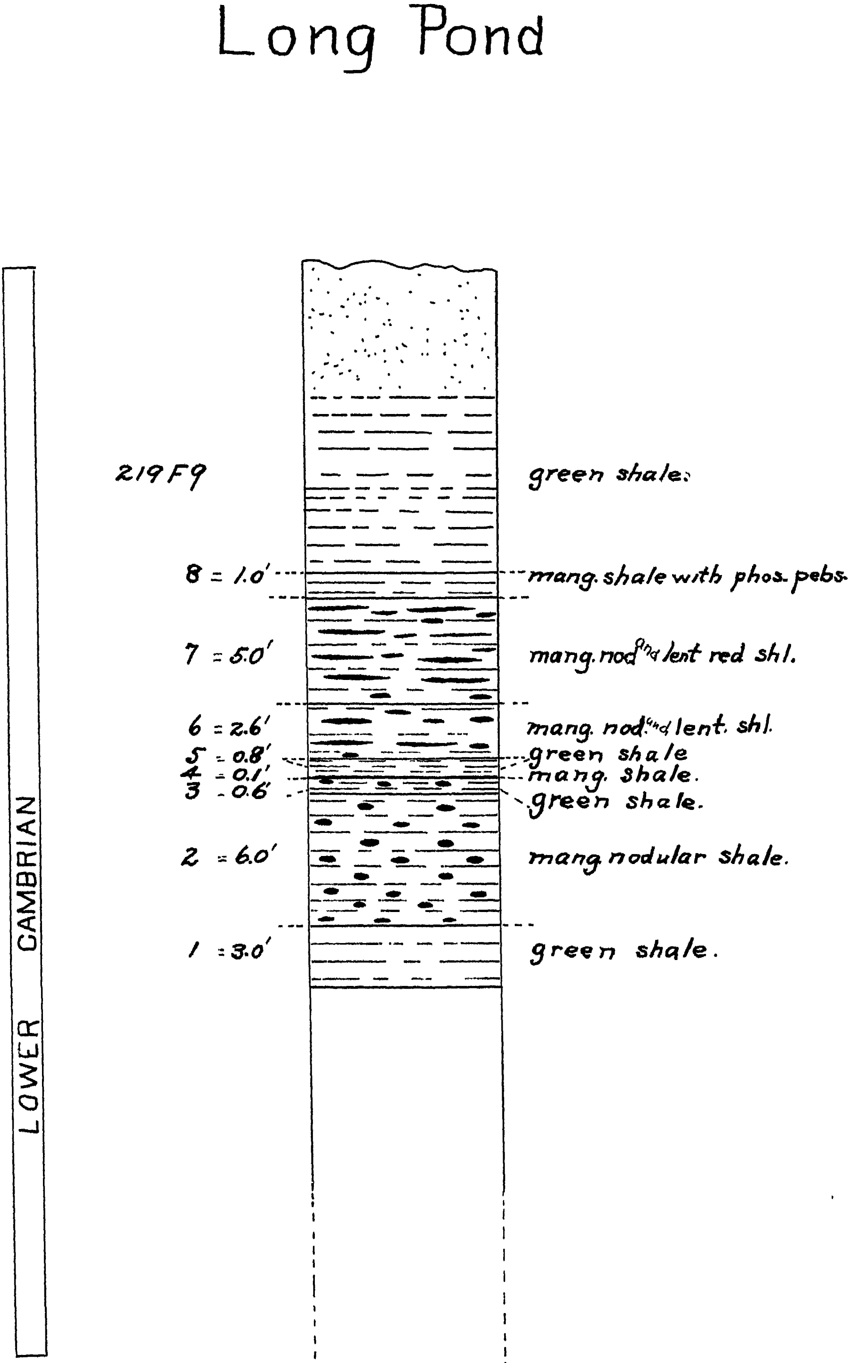


FIG. 36. Columnar section of the manganese zone at Long Pond; Loc. 219 F.

in great part shaly in composition. The nodules of this band suggest a very possible analogy to those of 219 A 5, 11, 12, 13, and B 5. In as much as this bed is somewhat phosphatic, the phosphate in all likelihood is associated with the nodules, as is the case with the nodules of 219 A 13 of Manuels. This bed is structurally and mineralogically quite similar to the phosphatic beds of Manuels.

Long Pond Section.—About 2½ miles southwest of Manuels and west of the railroad and wagon road (see Fig. 35), manganese occurs, in a low cliff, as nodular and banded layers interbedded with shales. Though the manganiferous beds at this locality are considerably more oxidized than those at Manuels, the occurrence as a whole is similar and it is necessary to present the section with only brief macroscopical descriptions of the important beds (Fig. 36).

Loc. Number.		Ft
219 F 10	Glacial mantle.	
9	Manganiferous green shale.	
8	Phosphatic nodular manganese shale	1.0
7	Manganiferous nodular and lenticular green shale	5.0
6	Banded nodular ore	2.6
5	Fissile green shale	0.8
4	Manganiferous banded ore	0.1
3	Massive nodular green shale	0.6
2	Nodular shale	6.0
1	Heavy green olive shale	3.0

219 F 2 of the above section corresponds quite closely to the lower nodular bed, 219 A 4a, of Manuels (see page 392), chiefly because of the presence of abundant discoidal-shaped nodules identical with those at Manuels. The nodules have altered for the most part to a wad and clay, some having secondary manganese or white clay centers and clay border zones and others with limonitic green clay centers with secondary manganiferous clay border zones. The weathered nodules are very abundant.

219 F 6 is a heavy manganiferous bed composed of several ½″ to 3″ red, brown and green manganiferous seams separated by thin nodular shale laminations that are now red. It is quite evident that this bed is a continuation of either 219 A 7 or 10 of Manuels. The interior of some of the weathered nodules is a red and green residual clay. The manganiferous seams weather reddish and greenish.

219 **F** 7 is probably a continuation of 219 A 8 and 9 of Manuels inasmuch as this bed is nodular and has many lenticular and continuous jaspery seams of 0.1 inch to 1 inch in thickness alternating with ½ inch to 1 inch seams of reddish manganiferous shale.

219 **F** 8 from its similarity to 219 A 13 of Manuels may be described as a phosphatic nodular manganiferous shale with the manganese in evidence as some hydrous oxide.

CHAPEL COVE SECTION.—The manganese at Chapel Cove, of inconsiderable amount, occurs in a very much faulted series of lower Cambrian limestones and shales as alteration products on many of the structural planes. If it were not for certain lithological analogies with the deposits just described it would hardly seem necessary to give any detailed description of this deposit because of the small quantity of manganese present (see Figs. 1 and 37).

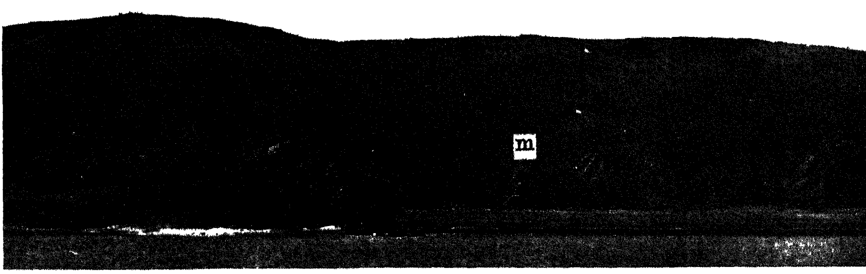


FIG. 37. Photograph of the section along the shore at Chapel Cove near Holyrood, Loc. 213 C; showing the managenese zone at (**m**).

The generalized section as worked out by Prof. G. van Ingen and Mr. A. O. Hayes during the summer of 1912 is as follows:

Loc. Number.		Ft
213 C 4 c	Olive green shale.	
b	Alternate pink layers with small black pebbles, manganese layer	3.6
a	Olive green shale, sheared near fault.	
C 3	Nodular limestone and shale	24.0
7	Argillaceous red limestone and alternating shales	25.0
6	Red shaly limestone	18.0
5	Red shale	8.0
D 7	Heavy red limestone	10.0
6	Red shales with limestone.	
5	Red and green limestone.	
4	Green limestone.	

E 2	Gray limestone.
1	Conglomerate with pebbles of syenite, black chert and limestone.
0	Syenite.
C 2	Agglomerate.
1	Ribbon slates. Conception slates (Huronian).

The section represents the stratigraphic sequence and the locality numbers indicate the position of the layers. Quoting Prof. van Ingen in regard to this most interesting locality:

"It appears to me that we have here the remnant of a squeezed syncline, the northern margin of which has been shoved far northwardly onto the underlying agglomerate and ribbon slates."

213 C 4b was studied more in detail by the writer during the summer of 1913 in the hope that some more definite knowledge might be gained on the occurrence of the manganese at this point, but without very much satisfaction. The subdivided manganese bed is as follows:

Loc. Number.	
213 L 4 c	Finely banded nodular bed.
b	Fractured and slickensided green shale.
213 L 4 a	Black nodular calcareous green shale with manganese staining.
L 3	Nodular ferruginous calcareous green shale with manganese stains.
2	Fractured and fissile shale.
1	Manganiferous calcareous green shale with hematite and pyrite.

In as much as the manganese was not visible to any great extent in its primary form throughout this small series of 3 to 4 feet no analysis was thought necessary. Two of the above beds, 213 L 3 and 213 L 4 are worthy of macroscopical and microscopical descriptions because of marked lithological resemblance to certain of the rocks at Manuels.

213 L 3 is a nodular shale with conspicuous calcareous ferruginous and manganiferous aggregations and jet black pebbles or nodular forms. All structural and divisional planes of this bed are conspicuously stained with some secondary oxide of manganese, probably a hydrated oxide such as psilomelane. Microscopical examination of this shale brings out the fact that the structure is nodular and oölitic and that the rock is a ferruginous chloritic shale.

The groundmass consists of chlorite and, for the most part, of an indeterminable material. Calcite occurs as an alteration product or as a constituent of the hematitic spherules. Quartz is found composing infrequent aggregates and as vein-filling material. The opaque minerals other than hematite are manganese as psilomelane or some other secondary derivative, pyrite as disseminations, and

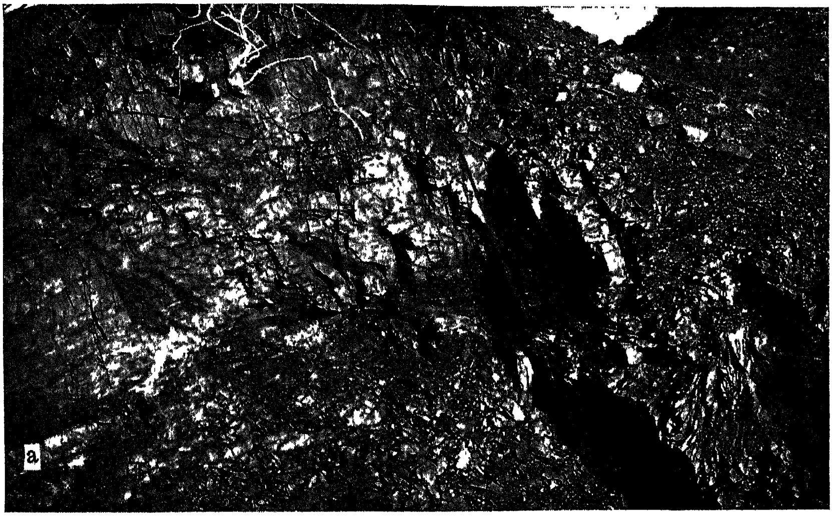


FIG. 38. Photograph of manganese prospect on Brigus South Head; Loc. 212 A12a. a, oxidized manganese beds; b, green shale.

limonite as a yellow staining. The spherules are for the most part hematite in composition but carbonate is a very common constituent. The diameters of the spherules range from 21 to 159 microns but average around 44 and 77 microns. The ferruginous centers of some of the spherules measure 0.8 of a micron.

Certain discoidal nodules in **213 L 4c** resemble those of 219 A 4 at Manuels though they are very much less abundant.

213 L 4a is nodular and the texture exceedingly fine-grained and locally crystalline. The greater portion of the thin section is probably composed of shale material and the remainder is taken up in great part by calcite and carbonate disseminations, as replacement material of hyolithes shells, or as mineral aggregates. Barite occurs

Fig. 39. View of Brigus South Head looking across the mouth of the harbor in a northerly direction and showing the position of the manganese zone (*a–a*).

as infrequent disseminations and individual platy crystals and probably once formed the *Hyolithes*-like rods now replaced by chlorite and a carbonate. Pyrite and hematite are found. The nodules of this bed, subspherical in shape, show under the microscope a compact

FIG. 40. View of the manganese beds (a) dipping into the sea on the east side of Brigus South Head.

structure and an almost impalpable fineness of grain. Under crossed nicols an occasional angular fragment of quartz is found but the groundmass as a whole appears to be isotropic. It is possible that these pebbles are analogous to the phosphate pebbles of Manuels, Topsail, and Long Pond.

Brigus Section.—At Brigus South Head on the west shore of Conception Bay (see Figs. 1, 38, 39, 40, and 41) manganese is found to a great extent in the oxidized state in several beds at the water's edge in the shales of lower Cambrian age which make up the sharp hog back ridge overlooking the "Needles." Because of the inac-

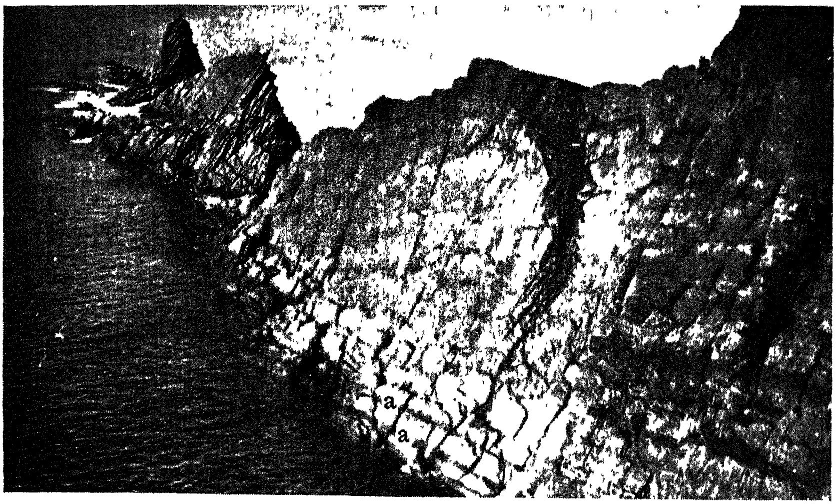


Fig. 41. View of the "Needles" at the extremity of Brigus South Head, showing the manganese zone (a–a).

cessibility of that portion of the ridge where the manganese was best preserved, detailed measurement of the section was not possible. Prof. van Ingen and Mr. A. O. Hayes in 1912 found that the best manganese measured about 4.5 feet thick in a zone of 15 feet. Specimens collected from more accessible portions were all practically altered to psilomelane but there is one which shows the original jaspery carbonate quite similar to the types described in connection with the Manuels occurrence. Several old prospect pits on the more accessible parts of this ridge were examined by the writer, but the manganese was found to be in its secondary state and the interbedded shales in a very much disturbed condition. The strike of the strata of this locality is N. 10 E. and the dip 47 E.

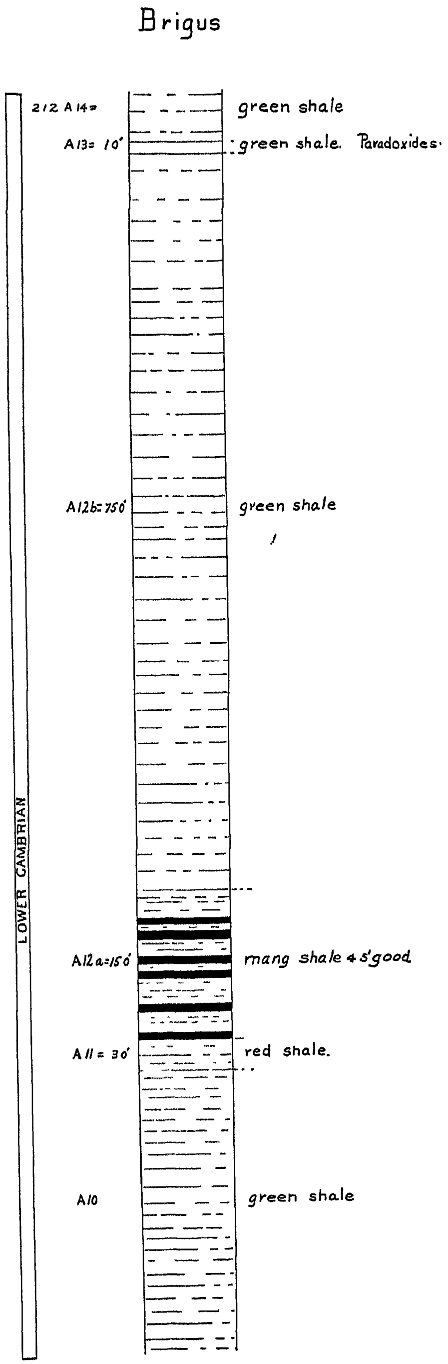


FIG. 42. Columnar section of a portion of the lower Cambrian at Brigus South Head, from measurements made by Gilbert van Ingen and A. O. Hayes, 1912.

The following section as prepared by Prof. van Ingen and Mr. A. O. Hayes from their study of the region in 1912 shows the stratigraphic relations of the manganese deposits at this point (Figs. 39 and 42).

Loc Number		Ft.
212 A 14	Green shales, end of needles	50.0
13	*Paradoxides* zone, green shales	1.0
212 A 12 b	Green shales	75.0
12 a	Manganese zone (4.5 ft. best)	15.0
11	Red shales, thin band	3.0
10	Green shale	60.0
9	Red shale	210.0
8	Red shaly limestone	11.6
7	Red shale	28.0
6	Limestone, heavy white at base, nodular and red above. *Holmia bröggeri* and other trilobites	30.0
5	Red shale	5.0
4	Limestone, very shaly	12.0
3	Red shale	32.0
2	Limestone with Cryptozoon	30.0
1	Red shale with local sandstone and conglomerate	50.0
	Unconformity.	
0	Pre-Cambrian shale and ash beds.	

The striking feature of this section is the position of the manganese zone in relation to the *Paradoxides* bed which is exactly the relation established at Manuels and undoubtedly at the other localities described.

Smith Sound Section, Trinity Bay.—The manganese zone on Trinity bay occurs at Smith Point (Fig. 1) as two massive beds associated with red and green nodular shales and limestones of lower Cambrian age. The accompanying map (Fig. 43), prepared from a transit survey of the shore line by Prof. van. Ingen during the summer of 1913, shows the structural and stratigraphic relations of the two manganese beds, 230 D 20 and D 27. The general strike of these beds is north and the dip, 20 west.

230 D 27, the important manganese bed of this section (Figs. 44, 45), measures some 38 inches in thickness, and is faulted with a downthrow of 15 feet on the west side. It is the thicker of the two manganese beds, and has been found by analysis to be essentially a

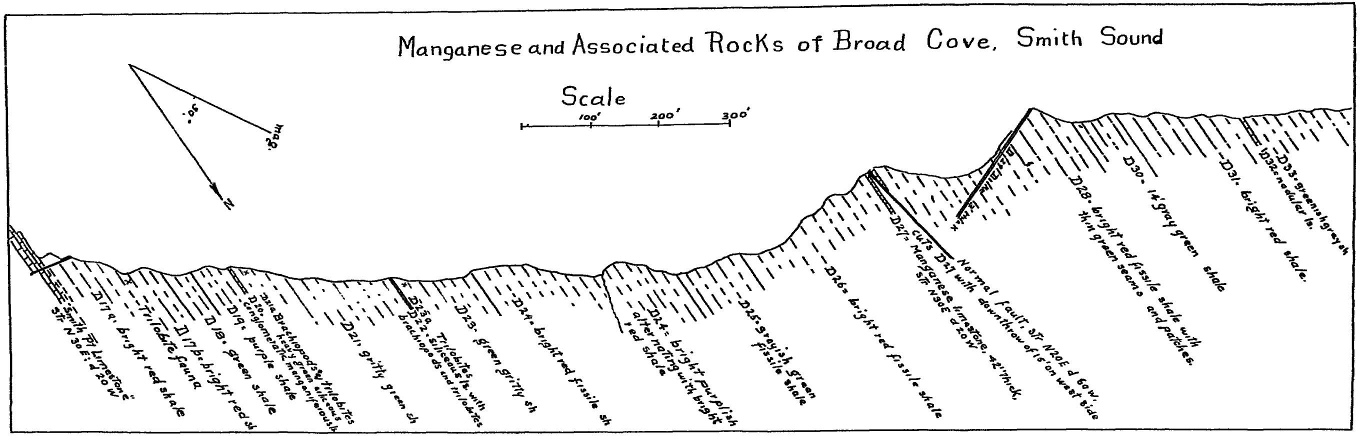


Fig. 43. Map of the outcrops of the protolenus and manganese zones exposed on the shore of Broad Cove, near Smith Point, Smith Sound, traced from field map based on stadia transit surveys by Gilbert van Ingen, 1913.

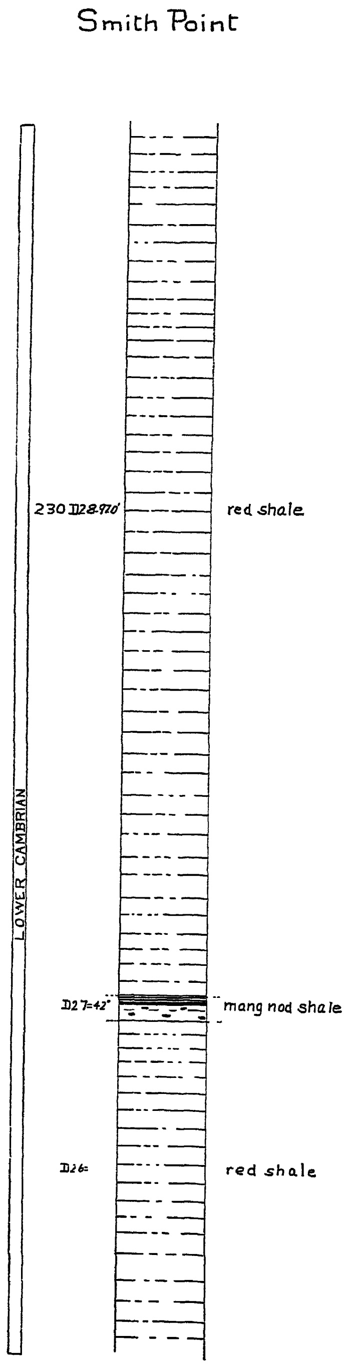


FIG. 44. Columnar section of a portion of the lower Cambrian at Broad Cove, near Smith Point, Smith Sound, Trinity Bay, Newfoundland, showing the manganese zone, 230 D26 to 28.

manganiferous dolomitic ferruginous shale. The bed is somewhat massive and nodular though the nodules are very irregular as compared with those at Manuels and other localities; irregular crystalline areas form the nodular portions while the matrix is made up of more argillaceous matter. Thin sections taken from the bottom and central portions of the bed were examined microscopically.

FIG. 45. Exposure of manganese ore, 230 D27, on the Broad Cove shore, near Smith Point, Smith Sound. This is a nodular ferro-manganese carbonate-oxide bed.

230 D 27aa is a reddish nodular and oölitic shale, with hematitic carbonate making up the greater portion of the determinable minerals; aggregations of a fine-grained dark material suggest phosphatic nodules so common in the Manuels occurrence. Irregular grains of quartz and aggregations of chlorite are found. Sections of trilobites and other organic forms containing carbonate material abound. Some hydrous manganic dioxide occurs (Fig. 47, Slide 299). Sections from the middle portions of the bed, **230 D 27e,** show a somewhat massive, nodular or oölitic reddish rock. Hematite is found as a pigment and to a lesser extent as lustrous opaque grains to which the color of the rock is due. A manganic oxide occurs as irregular and infrequent grains. Carbonate occurs as vein filling, as irregular areas, or as replacements of sponge spicules

Fig. 46. Nearer view of the ferro-manganese ore bed, 230 D27 on the Broad Cove shore.

and other organic bodies. Barite is found infrequently, sometimes with chlorite fringing it. Chlorite may be found replacing trilobite fragments.

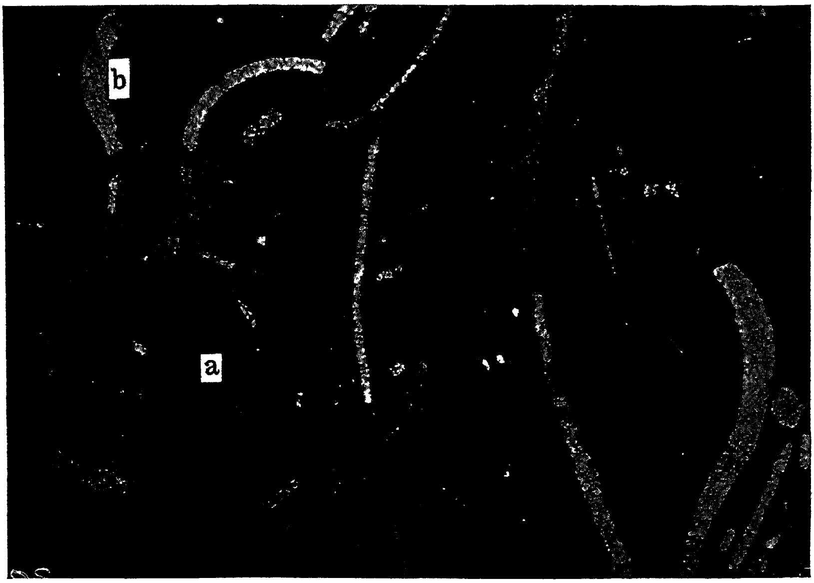


FIG. 47. Microphotograph of fossiliferous manganese ore, 230 D27; slide 299; from Broad Cove; enlarged 22 diam. a, manganese carbonate-oxide ore; b, fragment of trilobite test.

The following analysis and recalculation represent the chemical composition of an average sample of the bed and will corroborate some of the petrographic observations:

ANALYSIS *K*. *230 D 27*.		ANALYSIS *K* I. *Recalculation*.	
SiO_2	15.14	$MnCO_3$	26.91
Fe_2O_3	9.22	MnO_2	9.00
Al_2O_3	12.04	$CaCO_3$	15.21
MnO	25.63	$MgCO_3$	7.75
CaO	10.04	Fe_2O_3	9.22
MgO	3.72	$Ca_3(PO_4)_2$	2.50
P_2O_5	1.26	SiO_2	.84
H_2O	2.73	$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	30.06
CO_2	21.05		101.49
	100.83		

The manganese according to the recalculation of the analysis is essentially in the form of a rhodochrosite and whatever manganese there is in excess probably exists as a peroxide. It is quite possible that $Ca_3(PO_4)_2$ exists in the irregular black fine-grained areas, though nothing definite can be said in confirmation of it at this time.

Section of the Lower Cambrian from the Base of the Lower Paradoxides Zone down to the Top of the Smith Point Limestone, Trinity Bay (Fig. 47).

Loc. Number.		Ft.
230 D 32	Thin seams of nodular limestone in red shale	4.0
31	Bright red shale	46.0
30	Gray green shale	14.0
29	Dike	3.0
28	Bright red fissile shale with thin green seams and patches	97.0
27	Manganese limestone (manganiferous dolomitic shale)	3.5
26	Bright red fissile shale	78.0
25	Grayish green fissile shale	28.0
24	Bright purplish shale alternating with bright red shale	97.0
23	Green gritty shale	33.0
22	Gray band of fine grain silicious limestone full of pyrites and same brachiopods and trilobites	0.5
21	Gritty green shale, brachiopods and trilobites	62.0
20	Heavy green silicious conglomeratic manganiferous limestone	2.5
19	Purple shale	10.0
18	Green shale	10.0
17	Red shale	47.0
	b—Contains trilobite fauna ..... 13.0 ft.	
	a—Red shale 19.0	
	Interval covered 15.0	
16	Smith Point Limestone.	
	Total	535.5

V. OTHER MANGANESE DEPOSITS OF SOMEWHAT SIMILAR CHARACTER.

Sedimentary deposits of manganese are not of uncommon occurrence but it is rare that we find such deposits still in their unaltered condition as they were originally formed. There are however a few deposits elsewhere which in many respects resemble the Conception Bay and Smith Sound occurrences.

Newfoundland, Placentia Bay. In Placentia Bay, New-

foundland, manganese has been described by Murray and Howley as a massive carbonate bed interbedded with slates of "Silurian" age. Dr. T. Sterry Hunt (12: 204 and 205) described this mineral as

"compact and impalpable in texture, brittle, with a conchoidal fracture and a feeble waxy luster; slightly translucent on the thin edges; color fawn to pale chestnut-brown; streak white, hardness 4.0; density 3.25. The specimen shows faint lines which seem to be those of deposition and give to the mass the aspect of a sinter. It is encrusted and penetrated in parts with black crystalline oxide of manganese. The presence of oxide of manganese in this mineral is probably due to its partial decomposition." Analysis of this mineral by Dr. Hunt is as follows:

$MnCO_3$	84.6
SiO_2	14.40
Fe, CaO and MgO	traces

"This deposit is of interest on account of the existence of the metal in the form of a bedded carbonate. It probably represents the former condition of many of the oxide ores of manganese elsewhere in the stratified rocks, but they have since been converted to their more stable form."

It is quite evident from the above description of the Placentia Bay manganese that we have in all probability a deposit similar in mineralogic character and stratigraphic position to those in Conception Bay. No published stratigraphical or palæontological work has appeared on the Placentia Bay occurrences. In that portion of this paper relating to the stratigraphy of the manganese deposits it will be readily seen that the basin into which the manganiferous muds were deposited to form the present manganese beds of the lower Cambrian probably extended to or covered Placentia Bay or that portion of Placentia Bay where we now find Cambrian rocks. There is no doubt that the "Silurian rocks" referred to above by Howley and Murray are the lower Cambrian.

Wales.—Sedimentary manganese deposits have been described as occurring in the Cambrian rocks of Merionethshire, North Wales by Mr. Edward Halse (9: 156) in an article entitled, "The Occurrence of Manganese Ore in the Cambrian Rocks of Merionethshire." He says:

"in the Harlech mine, the bed of ore is a little over a foot thick, consisting of grit of medium grain, overlaid by a thin band of quartzite, probably meta-

morphosed grit. The roof proper consist of about 2 feet of very hard, schistose rocks, termed 'blue stone' by the miners. Specimens of ore taken from the mine are seen to be formed of uniform layers, having gray yellowish, white, greenish and chocolate-brown layers."

A reference by J. A. Phillips and Henry Louis (21:296) to the same occurrence is as follows:

"Beds of carbonate of manganese with some silicate, the outcrops of which have been to some extent changed into black oxide, occur intercalated between sandstones, grits and conglomerates of the Cambrian formation, and have been mined to some extent; the beds vary from one to two feet in thickness, and yield ore, averaging about twenty-seven per cent. of metal, which is used in spiegel making. These deposits are evidently symphytic and belong to group b of that class."

Phillips and Louis believe that these deposits were formed syngenetically but from precipitates in aqueous solutions. This deposit suggests very striking similarities to the Manuels occurrence not only mineralogically and genetically but also from the standpoint of stratigraphy.

ARKANSAS.—The Cason tract of the Batesville region, Arkansas, presents certain petrological analogies to the Newfoundland occurrences. Dr. Penrose (20: 219) describes the ore as occurring

"in lenticular layers, varying from an eighth of an inch to three inches in thickness, and interstratified with an indurated red clay of a slaty structure. Generally, however, the ore occurs in the shape of flat, lenticular concretions, from a quarter of an inch to one inch in diameter, locally known as 'button ore.' They have a concentric structure, are dull black on the outside and bright on the inside and are imbedded in a red or brown, fine-grained and more or less calcareous sandstone."

Analyses of the ore run as follows:

Mn	34.64	50.41
Fe	4.88	7.56
SiO_2	25.65	12.67
P_2O_5	0.58	0.06
Al_2O_3	3.79	1.37
CaO	5.13	2.00

Similar conditions to those postulated by Penrose for the accumulation of the manganese in the Arkansas region seem to me to be applicable to the Newfoundland deposits.

In writing of the circulation of the manganiferous solutions and the conditions under which they might be precipitated in the coastal shoals or lagoons, Penrose says (20: 590, 591):

"This gradual local accumulation of land and marine sediments would eventually cause shoals and possibly coastal lagoons and swamps, into which the waters from Archæan rocks of the Missouri Archipelago would drain."

"Here the solutions exposed in a stationary condition to the oxidizing and evaporating action of the atmosphere, would deposit their metalliferous contents as carbonate or possibly oxide of manganese. In some places considerable bodies of ore might be formed in one spot, in others the manganese would be dessiminated through the mechanical sediments being laid down at the same time. A secondary chemical action might cause the segregation of the disseminated manganese and the formation of concretions of carbonate of manganese, which would be later oxidized in forms such as are characteristically shown at the Cason mine, near Batesville, and elsewhere in the region. In other places the manganese might remain in a finely disseminated state, causing the common occurrence now seen throughout the region of an earthy manganiferous limestone containing from 3 to 15 per cent. of manganese."

SAXONY.—The writer was led to analyze certain of the manganese minerals from Schebenholz near Elbingerode in the Harz, which were purchased from Krantz, because of certain physical resemblances to the Newfoundland specimens. One specimen labelled "Allagite with Dialogite, etc." consists of three different materials; the first is greenish and gave the following analysis:

SiO_2	39.10	$MnSiO_3$	33.98
Fe_2O_3	1.87	$MnCO_3$	15.05
Al_2O_3	10.79	$MgCO_3$	12.64
MnO	27.69	$CaCO_3$	1.70
CaO	1.00	SiO_2	10.97
MgO	6.08	Fe_2O_3	1.75
H_2O	1.13	$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	23.76
CO_2	13.13		99.85
	100.79		

Unfortunately the early descriptions of this substance were not quoted very fully by later writers, but one of the imported specimens which was similar to the one analyzed had the following original label pasted on the back of it:

Grüner Allagite in Tomosite
eingewachsen.
73.71 Manganoxydulat.
16.00 Kieselerite.
7.50 Kohlensäure.
97.21
Schebenholz bei Elbingerode.

This analysis was published in 1817 and 1819 (Jashe 13: 1–12) and to all appearances is the same mineral analyzed by the writer, which is also labelled allagite.

Another part of the same specimen is a greenish jaspery mineral similar physically to the green band of the Newfoundland specimen and has the following composition:

		Recalculation.	
SiO_2	76.40	SiO_2	69.84
Fe_2O_3	.007	$MnCO_3$	10.00
Al_2O_3	2.46	$MnSiO_3$	8.00
MnO	10.53	$MgCO_3$	3.79
CaO	1.62	$CaCO_3$	2.80
MgO	1.81	$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	6.11
H_2O	.80		100.54
CO_2	7.32		
	100.947		

According to the recalculation this material is a manganiferous argillaceous chert, and is in all probability the silicious schist or shale of the Culm referred to later on.

The third portion of the specimen analyzed is a pinkish sparry mineral occurring as small veins with the following composition:

		Recalculation.	
SiO_2	7.10	$MnCO_3$	76.13
Fe_2O_3	.62	$MnSiO_3$	8.92
Al_2O_3	.76	$CaCO_3$	4.00
MnO	52.01	$MgCO_3$	2.44
CaO	2.26	SiO_2	2.16
MgO	1.17	Fe_2O_3	.37
H_2O	1.70	$2H_2O \cdot Al_2O_3 \cdot 2SiO_2$	5.98
CO_2	32.20		100.00
	97.82		

This mineral, because of its similarity to another specimen with

a label which reads "Spathiger Diallogit" pasted on it, is probably diallogit. It is however a very impure rhodochrosite.

According to W. Holzberger (11: 383) and C. Zerrenner (25: ?—) the ores from the Kaiser Franz mine near Elbingerode, in the Harz, occur as pocket-shaped intercalations a meter or so thick in the silicious shales of the Culm. The ore consists of psilomelane in dense and botryoidal masses, some pyrolusite and coatings of wad, with rhodonite, rhodochrosite and quartz present as accessories. The ore formerly worked contained on an average 60 to 63 per cent. of manganese peroxide, sometimes rising to 67 per cent. (23: 250). Zerrenner considers these manganese ores as later material separated out of the silicious shales, a theory which needs further investigation. Though the above described deposit is not the same as that from which the specimens analyzed above came from, it is no doubt similar.

The Elbingerode occurrence is similar to the deposits of SE. Newfoundland in that they are both primary manganiferous sediments. They differ in that the manganiferous zone of the former occurrence is considerably regionally metamorphosed while the Newfoundland sediments show very little change in this way. According to the above analyses, assuming that the imported specimens are representative of the region concerned, the deposits are very different in as much as they consist mostly of rhodonite and manganiferous cherts while those of Newfoundland are carbonate-oxides and oxide-carbonates of manganese.

VI. CHEMISTRY OF THE MANGANESE DEPOSITS.

The most striking feature of the accompanying analyses is the high content of MnO which ranges from 19.42 per cent. in **Analysis J**, to 49.25 per cent. in **Analysis D**, with an average content of 30.02 per cent and an average metallic manganese content of 24.64 per cent.

The manganese is present for the most part as the carbonate, $MnCO_3$ or rhodochrosite, which varies from 10.23 per cent. in the red band (**Anal. E**) to 44.39 per cent. in the green band (**Anal. A**) of the Manuels deposit. Rhodochrosite is not recognizable as such because of the impalpable fineness of grain of the deposit.

Solubility tests made of the red band (**Anal. E**) which has 27.61 per cent. of SiO_2, in which HCl was used as the solvent, show that the manganese must be present in some other combination than in that of the silicate, as the residue was about sufficient to cover the total silica, SiO_2, Al_2O_3 and P_2O_5. In **Anal. D,** it is evident that the two most important constituents are $MnCO_3$ and MnO_2 with percentages of 32.89 and 28.93 respectively and that the excess manganese calculated as the oxide is more than sufficient to form an important manganese silicate as the mineral percentage of SiO_2 is only 5.40, which fact lends support to the result of the solubility test made with the red band, **Anal. E.** A similar interpretation might be made with the Topsail ore (**Anal. I**) which is primarily an oxide ore with MnO_2— 34.25 and $MnCO_3$— 11.27. SiO_2, of which there is 10.32 per cent., probably is present in an uncombined state. The comparative instability of $MnCO_3$ would, however, lead one to suspect that the excess MnO_2, where not of primary origin, was a derivative of the carbonate and not combined with SiO_2 to form the silicate, $MnSiO_3$.

Analyses of Manganese Deposits of Newfoundland and Elbingerode.

	SiO_2.	Fe_2O_3.	FeO.	Al_2O_3.	MnO.	CaO.	MgO.	$BaSO_4$.	P_2O_5.	H_2O.	CO_2.	Total.
Manuels:												
A, Green band	7.24	3.36	3.21	6.11	35.53	11.30	2.30	....	.....	2.98	28.06	100.09
B, Pink nod. . .	5.14	1.40	....	1.64	20.49	32.92	.01	....	.....	1.65	36.77	100 02
C, Green nod. .	10.31	7.35	....	3.68	31.76	10.47	1.80	6.43	.....	2.85	25.31	99.96
D, Brown band	10.23	1.32	.89	4.14	49.25	8.11	3.02	....	.....	1.31	21.83	100.10
E, Red band . .	27.61	4.25	1.69	6.96	26.05	9.94	3.49	....	4.71	4.73	10.57	100.00
F, 219 A 11 . . .	18.42	6.33	....	7.95	21.44	14.46	5.01	....	3.46	2.58	21.20	100.85
G,* 219 A 3 . . .	58.62	3.12	3.66	22.42	.43	1.25	.26	....	.....	.54	3.99	94.29
H, 219 A 13. . .	25.20	10.13	....	7.67	.....	23.50	4.78	....	17.68	2.71	2.23	93.90
Topsail:												
I, 219 E 4.	18.04	4.82	....	6.58	41.26	2.24	2.39	5.40	.....	7.98	8.34	97.05
J, 219 E 6.	18.24	10.01	....	14.52	19.42	13.74	4.94	....	1.71	2.07	24.01	99.66
K, Smith Pt. . .	15.14	9.22	....	12.04	25.63	10.04	3.72	....	1.26	2.73	21.05	100.83
Elbingerode:												
L, Elbin. (−) .	39.10	1.87	....	10.79	27.69	1.00	6.08	....	.....	1.13	13.13	100.79
M, Elbin. (+)	76.40	.007	....	2.46	10.53	1.62	1.81	....	.....	.80	7.32	100.94
N, Elbin. (=).	7.10	.62	....	.76	52.01	2.26	1.17	....	.....	1.70	32.20	97.82

* Analyst, Mr. A. F. Buddington.

The evolution of Cl during the digestion of the samples with HCl is evidence that the excess Mn occurs as some peroxide. As

there is considerable water in the Topsail ore (**Anal. I**), the excess manganese probably is present as a hydrated peroxide such as psilomelane but probably in a very fine state of dissemination. The remarkable feature of the samples studied is the conspicuous absence of the dark oxides of manganese so far as macroscopic and microscopic observations are concerned but the reason for this may be, in the case of the lighter samples, anyway, that where there are abundant hematitic spherules there may be some masking. With the darker specimens studied, such as the red and brown bands at Manuels and the baritic manganese ore of Topsails (Figs. 22 and 32), the conspicuous manganiferous and ferruginous staining might easily mask finely disseminated particles of the peroxide of manganese.

RECALCULATED ANALYSES.

	$MnCO_3$.	$MnSiO_3$.	MnO_2.	$CaCO_3$.	$MgCO_3$.	$Ca_3(PO_4)_2$.	SiO_2.	Fe_2O_3.	$BaSO_4$.	H_2O.	Clay.	Total.
RA......	44.39	.....	8.08	20.11	4.21	.....	.....	3.36	....	.86	18.24	99.2
RB	29.32	.....	2.34	58.05	29.32	.....	3.78	1.40	....	1.06	4.07	100.02
RC	39.56	.....	7.30	18.61	3.79	.....	5.94	7.35	6.29	1.51	9.17	99.52
RD	32.89	.....	28.93	14.01	5.90	.....	5.40	1.27	....	.72	11.08	100.20
RE	10.23	.....	19.71	7.50	7.25	10.31	19.44	4.25	....	1.87	19.01	99.57
RF......	19.22	.....	9.36	18.61	10.54	7.50	9.18	6.22	....	.....	19.61	100.24
RG												
RH	.....	.....	.....	4.70	9.19	38.77	16.20	10.06	....	.....	19.11	98.03
RI	11.27	.....	34.25	4.00	4.97	.....	10.32	4.82	5.40	5.41	16.30	96.74
RJ	16.79	.....	.....	20.91	10.37	3.75	1.20	10.01	....	.....	36.38	99.41
RK	26.91	.....	9.00	15.21	7.75	2.50	.84	9.22	....	.....	30.06	101.49
ELBINGERODE												
RL......	15.05	33.98	.....	1.70	12.64	.....	10.97	1.75	....	.....	23.76	99.85
RM	10.00	8.00	.....	2.80	3.79	.....	69.84	.....	....	.....	6.11	100.54
RN	76.13	8.92	.....	4.00	2.44	....	2.16	.37	...	....	5.98	100.

The two most conspicuous mineral associations of the manganese deposits of southeastern Newfoundland are the tricalcium phosphate, $Ca_3(PO_4)_2$, and barite, $BaSO_4$. Only a few of the beds were analyzed for the former of these constituents where percentages of $Ca_3(PO_4)_2$ ranged from 2.50 at Smith Point (**Anal. K**) to 10.31 (**Anal. E**) at Manuels. **Anal. H** shows 38.77 per cent. of $Ca_3(PO_4)_2$, references to which are made on pages 409 and 453. It

is quite probable that others of the manganiferous beds analysed are phosphatic.

Barite ($BaSO_4$) is probably more common than the analyses indicate and is probably included with the SiO_2 and CaO. It is a conspicuous associate of these deposits, as has been found to be the case with manganese deposits in other parts of the world. The chemical reason for this association of two very different chemically-acting elements, as well as the genesis of barite are discussed on pages 451–453.

Al_2O_3, though not as abundant in the important manganiferous beds as in a typical shale, which that of **Anal. G** approximates, is of sufficient abundance to connect these deposits with the argillaceous sediments. CaO and MgO are in greater amounts than in ordinary shales, giving the deposits a calcareous or dolomitic character.

From a study of the mineral percentage composition of the samples analysed, the manganese rocks are found to be essentially calcareous or dolomitic argillaceous carbonates and oxides or carbonate-oxides of manganese, with hematite, barite, and tri-calcium phosphate as the chief accessories.

The following iron determinations of the green and red shales of the manganese zone at Manuels, Conception Bay, show some interesting results.

	FeO.	Fe_2O_3.
Red shale, 210 A 4	4.58	3.86
Green shale, 219 A 3	3.66	3.12
Red band, 219 A 7	1.69	4.25
Green band, 219 A 7	3.21	3.36

It is quite evident from the above analyses that the color in the green shale A 3 and in the green band A 7 is not due entirely to the ferrous iron as we find considerable Fe_2O_3 in both. In the green shale, A 3, there is an excess of .54 per cent. of FeO over the Fe_2O_3, while in the green band, which is manganiferous, there is an excess of .15 per cent. of the ferric oxide (hematite) over the ferrous oxide. In the green band we should expect a masking of the green by hematite inasmuch as there is such an excess of the ferric over the ferrous. Thin sections of this band and the green shale reveal some hematite but in very inconsiderable amounts; not enough, at

all events, to explain the percentages as brought out in the analyses. It would seem then that the ferric iron does not exist essentially as hematite but as a silicate or some other allied mineral, and that the green color so predominant in the manganese bands and shales may be due to the ferrous and ferric silicate.

The presence of hematite in the red band has undoubtedly caused the red coloration and the same may be said in reference to the red shale, 210 A 4, where there is an excess of .72 of FeO over the Fe_2O_3, but in these there undoubtedly has been sufficient masking of the ferrous and ferric silicates of iron by the hematite.

The production of the hematite was probably brought about by the conversion of the silicate into Fe_2O_3 through oxidation.

VII. GENESIS OF THE MANGANESE DEPOSITS AND ASSOCIATED MINERALS.

So many of the sedimentary manganese deposits described in the literature are in such a highly altered condition because of oxidation and deeper seated metamorphic influences whereby the original or primary manganese minerals have been so altered as to be of little genetic significance, that the carbonate-oxide manganese ores of southeast Newfoundland, which are surely primary ores, give promise of yielding evidence of considerable value on the question of genesis. In considering the genesis of any marine sedimentary manganese deposits, we are, however, confronted with many grave difficulties because we are dealing with submarine chemical conditions of which little is known and with diagenetic processes of which still less is known. It is also very difficult to advance any suitable chemical hypothesis founded upon some reaction that successfully works out in the laboratory which will not be of doubtful application in nature. With these difficulties in mind the following subjects relating to the genesis of the manganese deposits of southeast Newfoundland will be considered: Early Cambrian physiography; Nature of deposited sediments; Conditions under which the manganese deposits were formed; Summary of genesis of manganese; Diagenetic structures, as banded, nodular and oölitic; Genesis of barite; Genesis of tricalcium phosphate; Association and separation of iron.

Early Cambrian Physiography.—In all probability the area occupied by Trinity, Conception, Placentia, and St. Marys Bays, the included land and the western and eastern margins including the present known Cambrian outcrops, was a continuous body of water shortly after the beginning of the Cambrian transgression. West and east of this Cambrian sea were high and extensive pre-Cambrian land areas. The great crustal movements which threw the pre-Cambrian into mountain ranges probably converted the portion now occupied by the four bays and adjacent land into a narrow basin. The main topographic features of the southeastern part of Newfoundland during the beginning of the Cambrian were two land areas of great relief separated by a comparatively narrow trough which had a general north-south direction.

Whether this trough was a closed one or not, it would be difficult to prove, but from the requirements of the problem it is necessary to postulate a more or less closed basin or coastal shoals or lagoons, Concentration of manganiferous soluble salts could go on satisfactorily only in a more or less restricted shallow sea where the water was comparatively quiet. The facts that ripple marks occur occasionally in the deposits such as at Manuels and that a shallow water fauna abounds such as trilobites are sufficient indication that there was a shallow sea at this time.

Nature of Deposited Sediments.—Into this trough during early Cambrian times great quantities of mud were brought by rivers draining the pre-Cambrian land masses and to a lesser extent by the action of the waves on the shore line. As has already been stated the greater thickness of shales in the western portion of the basin is due to the fact that sedimentation had been going on for a longer time in that part of the basin which was in all probability the deeper part. It is also quite possible that the western parts of this trough were receiving more sediments than the eastern. The shales are characterized by their predominant red color in the western parts of the basin interbedded with shales of green color and throughout the entire area by a highly manganiferous zone.

Genesis of the Manganese Ore.—The distinctly bedded character of the manganese deposits and their occurrence in definite horizons of limited thickness and considerable horizontal range seem

to point clearly to the conclusion that the deposits are essentially of sedimentary origin, rather than products of a later ground water or weathering concentration. But beyond this conclusion, there is room for great diversity of opinion.

Two questions present themselves at the outset of the inquiry: Was the manganese deposited contemporaneously with the clastic sediments in its present degree of concentration? Or, was it somewhat disseminated through the muds and subsequently concentrated by diagenetic agents? While the first of these alternatives is held by the writer to be highly probable, no positive and final answer can be given to these and to many other questions raised by a study of the problem of genesis, although various suggestions are presented in the following pages.

Manganese exists in sea-water and has been noted by Forchhammer and by Dieulafait (6: 718) but not in sufficiently concentrated form to produce deposits similar to those under consideration. Murray and Irvine (19: 735) found that the red muds of the mid-Pacific and Indian Oceans, which were made up in large parts of basic vitreous volcanic minerals, were responsible for the large amounts of pulverulent and nodular ferromanganese. These nodules consist on the average of 29 per cent. of MnO_2 and 21 per cent. of Fe_2O_3 with the remainder largely clayey material. The basic glasses contain the only important primary manganese-bearing minerals in the ocean and the manganese is reported by Murray and Irvine to have undergone conversion into the soluble bicarbonate which upon reaching oxygenated surface waters, is decomposed with precipitation of the dioxide. The particles of MnO_2 falling to the bottom gather upon various objects which serve as nuclei for concretions, or the nuclei themselves may have been the cause for the precipitation. Murray and Hjort (17: 192) in this connection say:

> "It should be noted that these oxides need by no means necessarily assume a concretionary form. They are very commonly found as thin incrustations on granular and fragmentary objects. Furthermore many, if not most, of the pelagic clays contain intimate admixtures of finely divided brown manganese and occasionally of limonitic iron. Here the supersaturation would seem to have been so high as to transgress the metastable limit, whereupon the oxides have precipitated themselves without the intervention of nuclei; they certainly must have been precipitated from solution."

According to Leigh Fermor (8: 403) the origin of the deep-sea nodules is summed up as follows:

"1. The manganese, although probably partly derived from cosmic dust and volcanic débris, has been mostly precipitated from solution in the sea water, the manganese salts having been originally brought into the sea by rivers.

"2. The manganese oxide, although possibly partly precipitated as a result of the action of the vital processes of organisms, both vegetable and animal, has been mainly precipitated by calcium carbonate aided by the obscure process of segregation from solution round a nucleus.

"3. Where the sea-bottom consists largely of calcareous sediments, the precipitation may have been mainly brought about by the solution of some of this calcium carbonate with the deposition of an equivalent amount of manganese oxide owing to the presence of free oxygen.

"4. Where the sea-bottom consists of red clay, it does so because the depths are there so great that the tests of thin-shelled organisms are completely dissolved by the sea-water before they reach the bottom. The calcareous matter in being dissolved deposits an equivalent amount of manganese oxide, which descends to the bottom, and there acts as a nucleus for the segregative extraction of manganese from the waters at the sea-bottom. The deposition of manganese oxide by means of calcium carbonate associated with the red clays probably also occurs to a subordinate extent, for the shells of thick-shelled organisms may reach the bottom before being entirely dissolved."

This summary of Fermor's is quoted in full here because of the marked divergence of his views from those of Murray and Irvine, and because of the greater stress laid upon Penrose's idea of the precipitation of manganese oxide by calcium carbonate.

It is the belief of the writer that the early Cambrian Sea of southeastern Newfoundland must have had so restricted and shallow a character as to allow of a concentration of the manganese salts sufficient to form deposits of such dimensions and character as we now find. Whether the manganese was brought down entirely in solution or only partially so, or entirely or partly in mineral combination as fine muds from which the manganese was subsequently dissolved, one cannot say at present. Both muds and solutions probably have contributed the manganese which forms in great part the deposits as we now find them.

The conditions which brought about the formation of the carbonate and oxide of manganese are problematical. It is generally

supposed that manganese exists in solution as a bicarbonate or a sulphate. In their work on the Blue Muds of the Clyde Sea area, Murray and Irvine (19: 728) found that the bicarbonate of manganese was derived "first from the direct decomposition of the rock fragments in the mud by the alkaline carbonates in the sea water or, second, from the reduction of the higher oxides of manganese by the organic matter in the muds." In many respects the Clyde Sea area of England is similar to what the lower Cambrian sea of Newfoundland must have been. It receives detritus and waters draining lands which are in large part of an igneous and sedimentary character (19: 780).

"What is known as the Clyde Sea Area consists of a series of submarine basins, separated from each other by submarine barriers. The depth of the basins ranges from 30 to 106 fathoms, and the depth of water over the intervening ridges varies from 3 to 15 fathoms. In all the deeper parts of the basins there is a bluish mud, in which, as a rule, no manganese nodules are found, but on the immediate surface of the deposit of Blue Mud there is a surface layer with a reddish or light gray color, in which deposits of manganese dioxide occur. When stones are dredged from these muds many of them are surrounded by a dark ring of manganese dioxide, marking the depth to which they have been embedded in the mud. The whole upper surface of the stones has likewise a slight coating of manganese, while a portion imbedded in the mud is free from these manganese deposits."

He goes on to say that

"The formation of manganese nodules on the immediate surface of the deposit, on the tops of the barriers, and in the pit-like depressions, is most probably to be accounted for by the more abundant supply of oxygen, or the diminished amount of decomposing organic matter in these positions."

A somewhat similar set of conditions probably was present in the muds and superjacent sea water of the Cambrian basin of Newfoundland with the exception that instead of all the bicarbonate being converted into the dioxide the greater proportion of it was precipitated as the carbonate of manganese ($MnCO_3$). The liberation of CO_2 from the bicarbonate of calcium in solution has been experimentally effected by evaporation, increasing the temperature, or through agitation of the solution. It would seem to the writer that the liberation of the CO_2 from the manganese, calcium and magnesium bicarbonates might have taken place through evapora-

tion resulting in a contemporaneous formation of manganese, calcium and magnesium carbonate. As the analyses show from 1.25 to 32.92 per cent. of $CaCO_3$ and from .01 to 5.01 per cent. of $MgCO_3$ this would seem to support such an action.

There is a possibility that the decomposing organic matter present in the muds might have caused a deoxidation of the sulphates of the sea-water and of MnO_2 with the subsequent formation of FeS_2 and MnS_2. The latter, being very unstable, would pass immediately into the bicarbonate to be subsequently freed of its CO_2 to form the carbonate and if oxidized would pass into the dioxide. Such a process might account for the carbonates and oxides of manganese and the little pyrite that occurs. Though there is evidence of life in the manganese deposits of Newfoundland as furnished by the fossil trilobites, pteropods and phosphatic accumulations, we have no evidence that there was any great abundance. However these deposits resemble the Blue Muds studied by Dittmar (6: 43) which are a variety of terriginous deposit which

> "covers about 15,000,000 square miles of the sea bed, and is chiefly found in estuaries, harbours, enclosed seas, and along continental coasts where rivers pour their detrital matter into the ocean."

According to the "Challenger researches" there is an abundant fauna on these muds, which feeds chiefly on the organic remains that fall from surface waters. If any analogy can be made between the ancient terriginous deposits and the more modern ones such a chemical action as described above might very well have taken place.

If the muds on the bottom of the basin contained considerable quantities of decomposing organic matter, conditions would favor a reduction of the higher oxides of manganese, the evolution of much CO_2 and the consequent formation of the bicarbonate of manganese. The subsequent liberation of the excess CO_2 from the bicarbonate to form the carbonate and, where oxidizing influences are active, the oxidation of this carbonate would complete a series of reactions capable of forming the manganese deposits with which we are dealing. It is very probable that these muds contained considerable quantities of decomposing organic matter and were evolv-

ing considerable CO_2. According to the "Challenger researches," when a large quantity of carbonic acid was found in oceanic waters it was "at the bottom over Blue Muds." The great difficulty in this series of reactions is to find in nature the conditions which will bring about the liberation of the excess CO_2 from the bicarbonate to form the carbonate, such as evaporation, increase of temperature, or agitation. If quiet waters are postulated for the formation of manganese carbonate it is quite conceivable that either of the conditions such as evaporation or an increase of temperature might easily be obtained particularly in shoal waters. It is very doubtful, however, in the case of agitated waters whether laboratory conditions can be simulated in nature, because of oxidizing influences whereby some oxide of manganese would form more readily than a carbonate. After the carbonate had formed there would be no particular difficulty in conditions being present which would bring about the oxidation of the carbonate because of the presence of oxygen. The excess oxide of manganese found in the Newfoundland deposit may in part have originated in this way.

Penrose (20: 563) suggested that "carbonate of lime on the sea floor may have acted as a precipitating agent" or as it passes through the sea-waters in the form of organic remains or mineral particles a substitution takes place whereby a solution of the calcium carbonate with a corresponding precipitation of manganese occurs. Fermor develops this suggestion in his explanation of the origin of the deep sea nodules as quoted on page 444. Such an explanation might apply to the origin of the primary oxides of the Newfoundland deposits.

It is possible that manganese may have been present in the sea-water as a chloride. L. De Launay (5: 533) says that "manganese chloride with sodium bicarbonate produces manganese carbonate."

When we stop to consider that manganese only averages .07 per cent. of the lithosphere (Clark, 2: 32) and is 70 times less abundant than iron which averages 4.43 per cent. and compare with these figures the percentage of manganese in the deposits under consideration which is 24.64 we can obtain some idea of the enormous concentration there has been in the production of these deposits.

We have discussed the nature of the sediments and learned that these terriginous deposits must have been derived from the pre-Cambrian land masses which existed in far greater extent on the east and west of the Cambrian sea than the present areas outlined on page 373. The interbedded character of the manganiferous and argillaceous layers signify alternating conditions of chemical precipitation and mechanical deposition, there being, during the formation of the deposits, times when the Cambrian sea was more manganiferous with conditions such that precipitation of manganese carbonate and the oxide was the relatively important feature while, at other times, mechanical deposition of fine muds was the rule. It is more than likely that the greatest portion of the manganese was contributed to the sea in the form of the dissolved bicarbonate by the streams which transported the clastic sediments and that these sediments were not themselves responsible for the major contribution, though undoubtedly the manganese minerals in the muds underwent some solution both during their transit to the sea bottom and during diagenesis. The streams which were responsible for the transportation of the sediments of the manganese deposits and also held, as chief contributors of the manganese, drained the pre-Cambrian land areas above referred to. A modern river like the Ottawa which drains a pre-Cambrian area consisting in great part of Laurentian and Huronian rocks and in all probability not very different from the pre-Cambrian rivers of ancient Newfoundland, has .86 parts per million of manganese in its waters according to an analysis made in 1907 (Shutt, 22: 175).

Manganese in river water results from the solution of manganiferous silicates such as pyroxene, olivine, micas, amphiboles, epidotes and chlorites, some of which are the common and essential basic rock-forming minerals of any igneous and metamorphic pre-Cambrian area. On the decomposition of these elements the manganese is converted into carbonate or oxide and enters into solution, when conditions are favorable, as the bicarbonate, in which form it is carried to the sea, unless oxidized in transit, there to await the further changes into the oxides, MnO_2 and Mn_2O_3, or the carbonate, $MnCO_3$, depending upon the conditions suggested in the preceding pages. Analyses of some of the pre-Cambrian rocks in the vicinity

of Conception and Trinity Bays may be of interest at this point as illustrating the manganese content of some of the rocks which are most like those existing during the formation of the deposits:

	MnO
Monzonite, Woodford	.19
Quartz porphyry, Manuels	.11
Conception sl., Random Is.	.12
Granite, Manuels	.13
Aporhyolite, Manuels	.12
Basalt, Blue Hills	.48

Analyst, A. F. Buddington.

Similar analyses have been made from the rocks of the Clyde pre-Cambrian drainage area and show from .1 to .7 of a per cent. of MnO (Murray and Irvine, 19: 722). In all probability then the pre-Cambrian rocks on the east and west of the Cambrian basin were the ultimate source of the manganese.

Summary of Genesis of Manganese.

Ultimate Source of the manganese was the manganese-bearing silicates of pre-Cambrian igneous and metamorphic rocks east and west of the Cambrian Sea.

Solution of manganese-bearing silicates and conversion of the manganese into the soluble bicarbonate; under favorable conditions oxides of manganese resulted from the oxidation of the bicarbonate of manganese.

Transportation of the manganese chiefly as the bicarbonate and to a less extent as suspended particles of oxides by pre-Cambrian drainage systems to Cambrian basins.

Concentration of the salts of manganese chiefly as the bicarbonate in the sea-water immediately overlying the deposited muds.

Precipitation of manganese carbonate from solution through liberation of CO_2 from the bicarbonate, or of the oxide.

Clastic Origin of Some Manganese.—While the main contribution of the manganese came from the pre-Cambrian drainage area in solution undoubtedly the deposited muds supplied a minor portion.

Diagenetic Structures

Banded Structures.—By referring to the description of layer 219 A 7 we see that it is a red manganiferous shale with green and brown jaspery bands which may be rather uniform in thickness and may alternate with each other. The green band predominates over the brown so that the greater alternations occur with the green and red bands. Throughout the red shale are numerous nodules of the green and brown jaspery carbonate-oxides of manganese and within the bands themselves are nodular and concretionary forms. The alternating banded and concretionary forms within this bed would indicate alternating conditions of precipitation followed by diagenetic segregational processes which resulted in the formation of nodules and lenticles. Very thin and interrupted laminæ of the red band are found with the green bands. The green and brown bands often occur intergrown with each other. From these observations it would seem that these banded structures were evidence of alternate periods of precipitation and that they have assumed their present indurated and concretionary nature by segregational processes which were active throughout the diagenesis of the bed.

Nodules.—One of the most characteristic features of the shales of the Lower Cambrian is the great prevalence of the nodules (Figs. 14 and 15). The following suggestion is offered as to the origin of the form of these nodules with the hope that this line of investigation may be taken up in greater detail at some future time. Though various theories have been suggested for the origin of oölitic spherules and nodules, in general, along organic and inorganic lines, nothing of a very definite nature has been brought out as to the origin of their form. The suggestion that surface tension may be the cause of this form is here made. This peculiar and prevalent nodular character of certain beds was brought about in all probability by the tendency of surface tension to decrease the surface during the diagenetic stage. Solutions carrying manganese filtering through muds or nearly consolidated muds or shales would quite naturally under certain chemical and physical conditions have the tendency to decrease the surface tension at the contact of the three physical phases; liquid, colloid, and solid. Starting with a

mineral particle such as rhodochrosite or calcite as a nucleus, with the formation of the nodule, there will be a decrease in the concentration of the solution at the contact with the nodule which will be accompanied by a reduction of surface tension. If we are dealing with a liquid-liquid phase we would have a spherical nodule in which case both liquids would be easily deformable and the surface would tend to become a minimum. Our twofold phase, liquid-solid, or threefold phase including the colloidal phase which probably plays a part, only allows of deformability on the part of the liquid and partial deformability on the part of the nodule. Under the bedded conditions of this two or three fold solution, colloid and solid phase the tendency of the surface tension to reduce the surface to a minimum is well exemplified in the discoidal nodule.

Spherules.—One of the characteristic features of this deposit is the occurrence of hematite in spherule-like forms and larger, roughly spherical aggregates. Fig. 26 illustrates the occurrence. They differ decidedly from the spherules of the Wabana, Clinton, and other typical oölitic iron ores in that they are less symmetrical and are without any visible nuclei. These spherules are here described as incipient in as much as they seem to lack full development or to have been impeded in their growth. Such a retardation of development might have arisen from their growth in clayey sediments which were still unconsolidated.

Mineral Associations.—The three important mineral associaciations of the manganese deposits of S. E. Newfoundland are barite, tri-calcium phosphate and hematite which will now be considered with reference to their occurrence, association and genesis.

Barite.—Barite is one of the most characteristic mineral associations of the deposits under consideration as is often the case with manganese deposits elsewhere in the world. It is particularly characteristic of the Manuels, Topsail and Smith Point localities and occurs in various ways.

Barite is found in small veins crossing a cryptozoan nodule showing quite clearly its epigenetic character so far as that particular portion of the bed is concerned. Fig. 23 (Slide 276) shows a solitary crystal fragment of barite in a carbonate-oxide of man-

ganese groundmass showing possibly a diagenetic replacement. Barite also occurs as disseminated anhedral crystal grains or blades in the cores and outer zones of nodules at Manuels, which is very suggestive of diagenetic processes (Fig. 16, Slide 288). At Topsail (Fig. 31, Slide 269) barite occurs as bundles of blades or sheath-like aggregates in a manganese oxide groundmass strongly suggesting replacement.

In other parts of the world barium is often found replacing manganese in psilomelane and sometimes enters largely into the composition of wad, specimens from Romanèche containing as much as 16.2 per cent. of BaO (Dana, 3: 258). A very striking phenomenon shown by the barite is its replacement by chlorite (Fig. 12, Slide 296, and Fig. 34, Slide 272).

Just why there is this common association of two very unlike elements we have no definite information. De Launay (4: 52) gives the following explanation for epigenetic deposits:

> "The association between barite and manganese though very frequently exhibited in surface formations, in many cases these two substances are being concentrated by circulating waters in pockets or fissures of terranes."

Various conditions may produce barite with barium salts in solution but only one seems to apply to the occurrences under consideration. As there are evidences of diagenetically and epigenetically formed barite in the deposits, it is quite possible that there has been an intermingling of solutions carrying barium carbonate and some sulphate resulting in the formation of barite. According to De Launay (4: 52)

> "Barite being remarkably insoluble is one of those barium compounds which not only has the propensity to segregate and all at once to be transformed into the carbonate but also the tendency under the influence of H_2SO_4 produced by the superficial oxidation of the metallic sulphides to pass into the state of barite."

The replacement of the colorless barite by the pale green chlorite begins about the edges and along cleavage cracks of the former. The chlorite gradually spreads while the intervening portions of barite decrease until wholly eliminated, resulting in a pseudomorph of chlorite after barite. In general appearance of its various stages,

the process is quite like the serpentinization of olivine but differs essentially from the latter alteration in the fact that the secondary mineral, chlorite, derives none of its material from the original mineral, barite, its change involving a complete replacement by wholly new material. It is a marked example of the comparative ease with which substances which, like barium sulphate are regarded in the laboratory as very stable, yield to the attack of natural reagents.

This replacement seems to have accompanied a more or less general chloritization of the whole formation, at a period long subsequent to the concentration of the manganese ore and under totally different conditions.

PHOSPHATE.—Tri-calcium phosphate, $Ca_3(PO_4)_2$ also is a very conspicuous accessory of the manganese deposits of Newfoundland, averaging, for those beds of which analyses were made, about 6.0 per cent. and for the phosphatic nodules of the nodular bed overlying the manganese zone at Manuels, 38.77 per cent. When we stop to consider the amount of phosphorus in the lithosphere as .11 per cent. (Clark, 2: 32) the amount of concentration in these deposits, particularly in the nodules, becomes very noticeable and something of great interest. The similarity in chemical composition of the phosphatic nodules of Manuels brook and those of Hanford brook, N. B., has been referred to on page 409. As the writer has been unable to make as thorough a study of these nodules as he would have liked, it is hoped that at some future time the investigation may be continued. At this time then a very brief resumé of the modes of concentration of phosphorus may be of interest because of apparent application to the deposit under consideration.

According to De Launay (5: 646) there are three stages in the concentration of phosphatic deposits, namely solution of calcium phosphate, in which he considers that in surface conditions

"the constant presence of carbonic acid and sodium chloride or chlorhydrate of ammonia in the waters determines the solution of phosphate."

The second stage is that in which organisms play an important rôle.

"The faculty which live organisms have of throwing into very dilute solutions those substances which to them are necessary and of making them undergo a primary stage of concentration has played a great rôle for the phosphates." De Launay (5: 646).

The third stage called by De Launay, "Remises en mouvement" consists in a dissolution of the phosphate contained in preceding deposits which is followed by a reprecipitation of the same upon anything which has served as a center of attraction. The tendency in this mode of concentration is for the phosphate to become more and more like the original apatite in composition, the ultimate source of the phosphorus. It involves both a chemical and a mechanical action, the former in dissolution and reprecipitation and the latter in the formation of nodules which, according to the suggestion of the writer in connection with the manganese nodules of Manuels, may be of physical nature, namely the result of surface tension.

Iron.—An interesting, and yet problematical, point arises here in connection with the association and separation of iron and manganese as related to the manganese deposit under consideration. We should expect, in as much as both elements are taken into solution, that they both might be precipitated together as is sometimes the case with bog ores or. if separated, at no great stratigraphic distance. Because of their different rates of oxidation and different degrees of solubility, however, a separation is effected. Assuming both elements entering into solution contemporaneously, the iron would oxidize first, precipitating as Fe_2O_3, while the manganese, remaining in solution longer, is precipitated either as MnO_2, Mn_2O_3 or $MnCO_3$. Though the Newfoundland manganese deposits contain iron, it is much less in proportion to what it would be if both were precipitated together (see Analyses, p. 438) considering the relative abundance of the two elements in the lithosphere referred to on page 447.

VIII. BIBLIOGRAPHY.

1. Beck, Dr. R., and Weed, Walter H. 1909. The Nature of Ore Deposits. First edition, second impression; originally published in two volumes. Pp. 1–685. Illustrated. Hill Publishing Co., N. Y.
2. Clarke, F. W. 1911. Data of Geochemistry. Bull. No. 380 U. S. G. S., pp. 1–782.

3. Dana, J. D. 1909. The System of Mineralogy. Sixth edition, 4th thousand. By Edward Salisbury Dana. 1,400 figures with appendices I. and II., completing the work to 1909. 1,134 pages. 774 pages for 1st appendix and 114 for 2d appendix.
4. De Launay, L. 1897. Contribution a l'Étude des Gites Metalliferes. Extrait des Annales des Mines, P. Vicq-Dunod et Cie, Editeurs, Paris.
5. De Launay, L. 1913. Traite de Metallogenie Gites Mineraux et Metalliferes Gisements, Recherche, Production et Commerce des Mineraux utiles et Minerais, Description des Principales Mines, Tome I., II. and III. Librarie Polytechnique, Ch. Beranger, Editeur, Paris et Liege.
6. Dieulafait. 1883. Compt. Rend., Vol. 96 (cited).
7. Dittmar, Rudolf. Challenger Report on the Composition of Ocean Water, Phys. Chem. Chall. Exp., pt. 1.
8. Fermor, Leigh. 1909. The Manganese Ore Deposits of India (with plates 8 to 16), Vol. XXXVII. London: Messrs. Kegan Paul, Trench, Trubner & Co.
9. Halse, Edward. 1887. Mineral Resources, U. S.
10. Harder, E. C. 1910. Manganese Deposits of the U. S. with Sections on Foreign Deposits, Chemistry and Uses. Bull. 427 U. S. G. S., pp. 1–298; 2 plates and 33 figures. Complete bibliography.
11. Holzberger. 1859. Neues vorkommen von Manganerzen bei Elbingerode am Harze; Berg- und Hütten. Ztg. XVIII.
12. Hunt, T. Sterry. 1857–58. Geol. Survey of Canada.
13. Jashe. 1817. Kleine mineralogische Schriften, Sondershauen, pp. 1–12.
14. Lindgren, Waldemar. 1913. Mineral Deposits. 883 pages. McGraw-Hill Book Co.
15. Matthew, W. D. 1893. On Phosphate Nodules from the Cambrian of Southern New Brunswick. Trans. N. Y. Acad. Sci., Vol. XII. Reprint. Contribution from the Geological Department of Columbia College, No. 9.
16. Matthew, G. F. 1895. The Protolenus Fauna. Trans. N. Y. Acad. Sci., Vol. XIV., pp. 101–153.
17. Murray, Sir John, and Hjort, Dr. John. 1913. Depths of the Ocean, pp. 821, 4 maps, 9 plates.
18. Murray, Alex., and Howley, Jas. P. 1881. Geol. Survey of Newfoundland, pages 1–536. London.
19. Murray, John, and Irvine, Robert. 1893. On the Chemical Changes which Take Place in the Composition of the Sea Water Associated with Blue Muds on the Floor of the Ocean. Trans. Roy. Soc., Edinburgh, Vol. 37, pp. 481–508.
19a. Murray, John, and Irvine, Robert. 1894. On Manganese Oxides and Manganese Nodules in Marine Deposits. Trans. Roy. Soc., Edinburgh, Vol. 37, pp. 721–742.
20. Penrose, R. A. F., Jr. 1891. Manganese: Its Uses, Ores, and Deposits. Am. Rept. Geöl. Survey of Ark. for 1890, Vol. 1, pages 1–642.
21. Phillips, J. Arthur. 1896. A Treatise on Ore Deposits. 2d edition re-

written and greatly enlarged by Henry Louis. Pages 1–943. With numerous illustrations. Macmillan and Co., London.

22. Shutt, Frank T., and Spencer, Gordan A. 1908. The Mineral Constituents of the Ottawa Water. 1908. Proc. and Trans. Roy. Soc. Can., 3d series, Vol. II. Meeting of May, 1908.
23. Stelzner, A. W., und Bergeat, A. 1904–1906. Die Erzlagerstätten, 1 Hälfte. mit 100 Abbildungen und einer Karte. Verlag von Arthur Felix, Leipzig.
24. Walcott, C. D. 1899. Pre-Cambrian Fossiliferous Formations. Bull. Geol. Soc. of America, Vol. 10, pp. 199–244. Pls. 22–28.
25. Zerrenner, C. 1861. Die Manganerz-Bergbaue in Deutschland, Frankreich und Spanien: Frieberg. (Cited by Stelzner und Bergeat.)

PRINCETON UNIVERSITY,
June, 1914.

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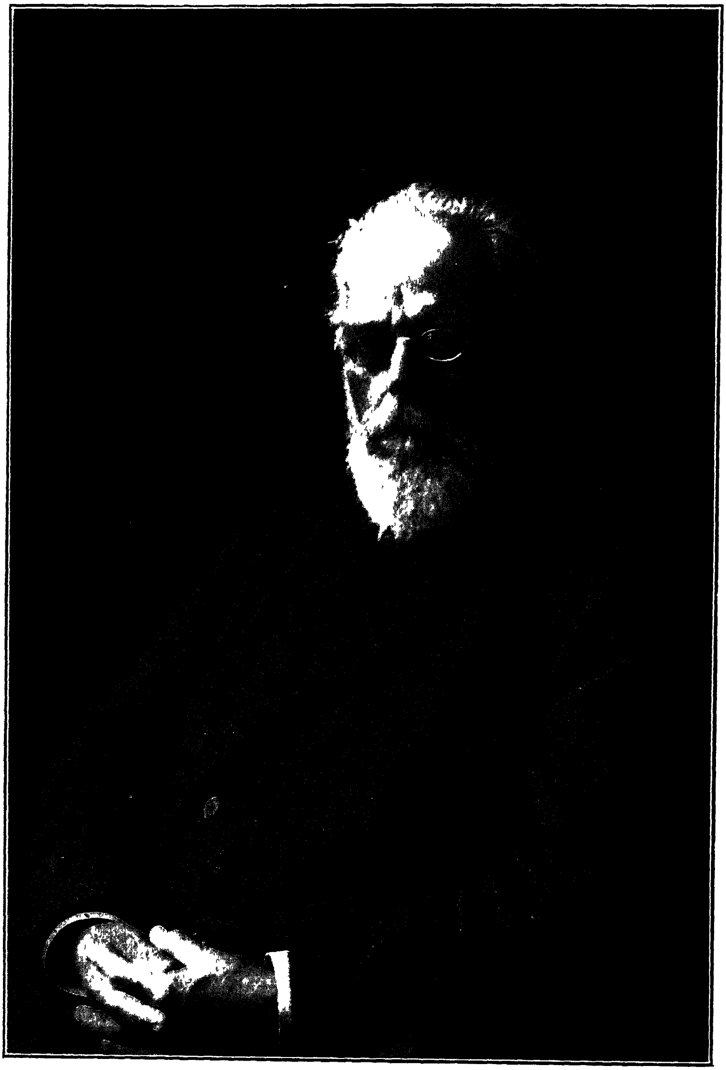

AUGUST WEISMANN.

BORN JANUARY 17, 1834. DIED NOVEMBER 6, 1914.

AUGUST WEISMANN.

PLATE A.

(*Read January 1, 1915.*)

August Weismann, a foreign member of this Society, was born at Frankfort on the Main, January 17, 1834, and died at Freiburg in Breisgau, November 6, 1914. He early showed the traits of a naturalist and in one of his books speaks of the excitement he felt as a boy in catching butterflies. He attended the University of Göttingen, where he studied chemistry and medicine, coming especially under the instruction of the distinguished anatomist Henle, and receiving the degree of M.D. in 1856. After spending three years at Rostock as an assistant he began the practice of medicine at Frankfort and during this time he visited Vienna in 1858, Italy in 1859 and Paris in 1860. From 1861 to 1862 he was private physician to Archduke Stephan of Austria at Schamburg Palace. He then studied zoölogy at Giessen under the renowned zoölogist Leuckart and became *privat-docent* in zoölogy at the University of Freiburg in 1863, where he spent the remainder of his life. In 1866 he was appointed *professor extraordinarius* and a few years later became *professor ordinarius,* which position he continued to hold until a few years before his death, when he was made *professor emeritus.*

In person he was a man of striking appearance, being about six feet tall and well proportioned and having a fine head and face and an earnest but kind expression of the eyes. From 1864 to 1874 and again from 1884 on he suffered from an eye trouble which interfered greatly with his microscopical work and turned his attention to theoretical questions. One of his former students and assistants, Professor Alexander Petrunkewitch,[1] to whom I am indebted for much valuable information concerning his personality,

[1] I am also indebted to Prof. H. H. Wilder, of Smith College, and to Prof. J. S. Kingsley, of the University of Illinois, for information regarding the family life and personality of Weismann.

says that although he was usually quiet in manner he invariably became nervous and unhappy in the presence of moving objects, which painfully affected his eyes.

A short autobiography published in *Lamp* in 1903 gives a glimpse of his family life:

> "During the ten years (1864–1874) of enforced inactivity and rest occurred my marriage to Fraulein Marie Gruber, who became the mother of my children and was my true companion for twenty years until her death. Of her now I think only with love and gratitude. She was the one who more than any one else helped me through the gloom of this period. She read much to me at this time, for she read aloud excellently, and she not only took an interest in my theoretical and experimental work but she also gave practical assistance in it."[2]

His great work on the "Natural History of the Daphnoidea" (1876–79) is dedicated to "My father-in-law, Adolph Gruber, in thankful memory of the beautiful hours of leisure spent on the shores of Bodensee." His colleague, the anatomist Wiedersheim, married another daughter of Gruber who was a Genoese banker. After the death of his first wife Weismann married again when about sixty years old, but not happily. One of his daughters married the zoölogist W. N. Parker, who translated into English his best known work "The Germ Plasm." A son was trained as a professional violinist.

Weismann, like so many other naturalists, was of an artistic disposition. He loved nature, art and music and he was an accomplished pianist. During the periods when he suffered much from his eye trouble he says that he "found solace in playing a good deal of music." He was an enthusiastic admirer of Beethoven but could not appreciate Wagner. His artistic temperament is further shown in many of his essays which for beauty of expression are rarely surpassed in scientific literature.

He was an excellent speaker, being simple and earnest in manner and never indulging in jokes. His lectures on evolution, which were delivered regularly for almost forty years, were famous and always attracted great audiences. As a teacher of advanced students he was stimulating and helpful, a kind critic and an attentive listener.

He took no active part in politics, but like many German pro-

[2] Quoted from Locy's "Biology and its Makers," p. 401.

fessors was a member of the "National Liberal" party. In philosophy he held tenaciously to a mechanistic conception of nature, but he believed that extreme mechanism was consistent with extreme teleology, indeed he held that "The most complete mechanism conceivable is likewise the most complete teleology conceivable. With this conception vanish all apprehensions that the new views of evolution would cause man to lose the best that he possesses—morality and purely human culture." In his philosophy as in his scientific controversies he was extremely tolerant. He was interested in the promotion of knowledge but was not aggressive nor offensive in manner.

Inasmuch as his life was so largely given to the extension and support of the Darwinian theory it is interesting to hear from himself how that theory first came to his attention. After remarking, "I never heard evolution referred to in my student days," he describes the influence on himself of Darwin's book in these words:

> "I myself was at the time in the stage of metamorphosis from a physician to a zoologist, and as far as philosophical views of nature were concerned I was a blank sheet of paper, a *tabula rasa.* I read the book ["Origin of Species"] first in 1861 at a single sitting (*sic*) and with ever growing enthusiasm. When I had finished I stood firm on the basis of the evolution theory, and I have never seen reason to forsake it."

With just pride he mentions the fact that he was one of the first scientific men in Germany to defend publicly Darwin's theory; Fritz Müller was the first to publish a work in favor of that theory ("Für Darwin," 1864), Haeckel was the second ("Generelle Morphologie," 1866) and Weismann was the third, his Inaugural Address at Freiburg on the "Justification of the Darwinian Theory" ("Über die Berechtigung der Darwin'schen Theorie") being published in 1868.

Thereafter his contributions to the Darwinian theory were numerous and important. They appeared from 1872 to 1902 as a series of books and contributions. Five of these earlier contributions were translated into English by R. Meldola and were published as two large volumes in 1882 with an introduction by Charles Darwin. Subsequent studies on evolution were so intimately associated with his theories of heredity that they can best be considered under that topic.

Weismann's contributions to biological theory were so extensive and important that they overshadow to a great extent his observational and experimental work, and yet the latter was by no means small or unimportant. Among these observational and experimental studies must be mentioned especially his extensive works on "The Development of Diptera (1865)," "Natural History of the Daphnoidea" (1876–79), "Origin of the Sex Cells of the Hydromedusæ (1883)," "Seasonal Dimorphism of Butterflies" (1875), "Origin of Markings of Caterpillars" (1876) and "Transformation of the Mexican Axolotl into Amblystoma."

Some of his earlier work was done without assistance, but in all of his later observational and experimental studies he had the assistance of his wife or other helpers. Much of his work was done in collaboration with some of his students or assistants. His method of work was to a large extent forced upon him by his eye affliction. After 1864 all reading had to be done for him, at first by his wife and after her death by a secretary. Experimental work was done under his supervision by his assistant and janitor. All microscopic work was done by his pupils, to whom he suggested topics and whose work he supervised daily. These theses were always in direct relation to his theories and to that phase of them which interested him most at the moment.

But valuable as much of his observational and experimental work was, there is no doubt that he will be remembered chiefly for his theories of heredity. His earliest writings on this subject date from the year 1883 and his latest were published but a few years before his death. His "Essays upon Heredity and Kindred Biological Topics" were translated into English and published in two volumes in 1889 and 1892. Probably his most important work on this subject is his book entitled "The Germ-Plasm, A Theory of Heredity" which was published in English in 1893. Subsequent works on heredity are "On Germinal Selection" (1896) and "Vorträge über Descendenztheorie" (1902). This last-named work, which was published in English under the title "The Evolution Theory" (1904), consists of a summary and an expansion of many of his previous writings on the subjects of evolution and heredity;

indeed as he says in the preface of this book, it is "a mirror of the course of my own intellectual evolution."

Without attempting to analyze these different books, which would require more time and space than is here available, we may proceed at once to a summary of his more important contributions to the theories of evolution and heredity.

All his theories, both of heredity and evolution, center in what he called the "germ-plasm," that particular part of the germ cells which serves to carry over from generation to generation the inheritance factors. This germ-plasm was held by Weismann to be absolutely *continuous* from the present generation back to the earliest generations of living things; it was absolutely *distinct* from the somatoplasm of the body and the latter could never become germ-plasm; it was almost perfectly *stable* undergoing practically no changes except such as came from the mixing of different kinds of germ-plasm (amphimixis) in sexual reproduction.

These views as to the nature of the germ-plasm underwent some modification as the result of criticism. Weismann was forced to admit that the distinctness and stability of the germ-plasm were not absolute, but in spite of all criticism he was able to maintain that the germ-plasm was relatively very distinct from other plasms and very stable in organization and this is now admitted by all persons acquainted with the subject.

His views as to the separateness of somatoplasm and germ-plasm, of body cells and germ cells, and the mortality of the former and potential immortality of the latter, led him to regard organisms in which this distinction does not exist (many protozoa and protophyta) as potentially immortal. With a keenness of insight which was not appreciated at the time but which has been confirmed by recent work he reasoned that "conjugation like food and oxygen may be conditions of life but immortality does not rest on the magic of conjugation any more than on food or oxygen." Again he anticipated the most recent opinions when he held that death is not a necessary correlative of life, but rather the result of higher differentiation. In short, as Minot said, "Death is the price we pay for our differentiation." On the other hand, his attempt to

explain the origin of death as an adaptation due to selection was probably a mistaken one.

As to the location of the germ-plasm in the sex cells Weismann maintained that it was to be found in the chromatic substance of the nucleus. He held that the chromosomes ("idants") were composed of smaller units, the chromomeres ("ids"), and that the latter were composed of "determinants" or inheritance units, while the most elementary units of life he called "biophores." Both chromosomes and chromomeres are visible structures of the cell. Determinants and biophores are ultra-microscopic in size but recent work on heredity and development has shown that there is good evidence of the existence of such units. All recent work in genetics is based upon the hypothesis that there are units or factors or determiners in germ cells which condition the development of adult characters, and though there may be minor differences between these *determiners* of modern genetics and the *determinants* of Weismann no one can fail to note the genetic connection and the family resemblance between the two.

His prediction on purely *a priori* grounds that one of the maturation divisions in the formation of the egg and sperm should be a "reduction division" whereby the chromosomes of the sex cells should be reduced to half the number present in the somatic cells, whereas all other cell divisions should be "equation divisions" in which the chromosomes should divide equally, was almost as brilliant an example of scientific prophecy as was the prediction of the existence of the planet Neptune.

Similarly Weismann's assumption that the determinants are arranged in a linear series in the chromosomes finds strong support in the newest and most striking discoveries in this field, in which Morgan is able to locate at different points along the length of a chromosome the determiners of many developed characters.

Finally there is at present universal agreement to the declaration of Weismann that no purely epigenetic theory of heredity is possible, though for many years even this was hotly contested. When one recalls the storm of opposition which was called forth by his book on "The Germ-Plasm" the present acceptance, at least

in principle, of his major propositions cannot be viewed in any other light than as a triumph for his theory and a tribute to the insight, foresight and constructive ability of Weismann.

As a result of his theory of heredity Weismann was led to investigate the generally accepted doctrine of the inheritance of acquired characters. He carried on extensive experiments in order to learn whether mutilations of parents through many generations were ever inherited by offspring; he investigated many supposed cases of the inheritance of such characters, and as a result of this work he was led to deny altogether the possibility of the inheritance of acquired characters, and he challenged the world to furnish any satisfactory proof of such inheritance. This work of Weismann's called forth a tremendous amount of discussion and a relatively small amount of direct observation and experiment, and for several years it appeared as if no progress whatever was being made toward the solution of this great question, so full of importance, not merely for the biologist but also for the practical breeder and indeed for the human race. But gradually there has grown up a clearer understanding of the problem and of what is meant by "inherited" and "acquired" characters, and gradually this dead-lock of opinions is breaking up. Now we recognize that inherited characters are those whose distinctive or differential causes are in the germ cells, while acquired characters are those whose differential causes are environmental. No one today believes that the developed or somatic characters of an organism are transmitted to the next generation. Today the problem of the inheritance of acquired characters is merely this: Can changes in the environment change the constitution of the germ-plasm so as to produce changes in subsequent generations? No one now asks whether changes in developed characters may be transmitted to descendants, as was generally done before Weismann's work, for it is generally recognized that somatic characters whether inherited or acquired are not transmitted from generation to generation, the only thing which is transmitted being the germ-plasm. Weismann admitted in his later writings that the germ-plasm might be modified to a limited extent by certain environmental conditions, but he held that such

changes of the germ-plasm led to general and unpredictable changes in future generations which might be wholly different from those somatic changes in the parents which were directly produced by such environment. This view is now widely accepted.

Thus while Weismann's views on this subject underwent certain changes in the course of his long life, the opinions of his opponents have undergone so much greater and more important changes that it may be truly said that in the matter of the inheritance or non-inheritance of acquired characters the greater portion of the scientific world has come to Weismann's position.

Finally mention must be made of Weismann's theory of evolution which was a direct outgrowth of his theory of heredity. He maintained that evolution must depend upon an evolution of the germ-plasm and that this was brought about chiefly, if not entirely, by the mixture of different kinds of germ-plasms (amphimixis) in the union of the sex cells. There is no doubt that many variations are produced by amphimixis but in general these combinations of germ-plasms are not actual fusions; new combinations of inheritance units are produced but not new units, and usually these new combinations split up in subsequent generations according to Mendelian rules, so that such temporary combinations of different germ-plasms do not usually lead to permanent modification, or to evolution, of the germ-plasm. On the other hand it is probable that Weismann underestimated the possible influence of environment in producing changes in the germ-plasm and hence its influence on evolution; at least it does not seem possible at present to explain the origin of many inherited mutations except by the influence of changed environment upon the developing germ cells.

In his belief in Natural Selection Weismann out-Darwined Darwin or any of the Darwinians. Darwin dealt only with the survival of individuals or races in the struggle for existence and was always inclined to assign a good deal of weight to the influence of environment in producing new races. Weismann would not admit the existence of any other factor of evolution than selection and he extended this principle from individuals or persons ("personal selection") to organs and tissues ("histonal selection") and

even to germinal units such as determinants and biophores ("germinal selection"). By means of an assumed struggle for nutriment between different determinants he believed that the weaker ones would tend to grow still weaker and to disappear while the stronger ones would increase in strength until they reached such importance that they were checked, or increased, by personal selection. And by a similar struggle between different biophores he showed that the *quality* of a determinant would be changed. By means of this highly ingenious but purely formal and hypothetical system he was able to explain the degeneration and disappearance of useless parts of an organism and the concordant modification of many different parts in the course of evolution.

Of all his theories those which grew out of his belief in the "Omnipotence of Selection" have found least confirmation in subsequent work. The Mutation Theory of deVries has come in to modify in certain important respects the theory of Darwin, and the work of Johannsen, Jennings, Pearl and others has shown that even "personal selection" has little or no influence in *creating* new types. And yet we have not seen the end of the selection doctrine. The elimination of the unfit is still the only natural means of accounting for fitness in organisms and we may well ponder these words of Weismann in the preface of his last book:

> "Although I may have erred in many single questions which the future will have to determine, in the foundation of my ideas I have certainly not erred. The selection principle controls in fact all categories of life units. It does not create the primary variations but it does determine the paths of development which these follow from beginning to end, and therewith all differentiations, all advances of organization and finally the general course of development of organisms on our earth, for everything in the living world rests on adaptation."

Clear thinking is necessary in the advance of science as well as fine technique and Weismann has demonstrated to a more or less scornful world the importance of brains as well as of hands and eyes in the discovery of truth. It does not fall to the lot of any man to make no mistakes, and in this respect Weismann was only human. But it has fallen to the lot of few men to do so much work of lasting value and to have so profound an influence on his

day and generation as was true of August Weismann. The spirit of his life and work may be summed up in the beautiful words with which he closes his essay on "Life and Death": "After all it is the quest after perfected truth, not its possession, that falls to our lot, that gladdens us, fills up the measure of our life, nay! hallows it."

EDWIN G. CONKLIN.

PRINCETON UNIVERSITY,
January, 1915.

MINUTES

MINUTES.

Stated Meeting January 1, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of Charles Martin Hall, A.M., LL.D., of Niagara Falls, at Daytona, Florida, on December 27, 1914; æt. 51.

Prof. Edwin G. Conklin read an obituary notice of Prof. August Weismann.

Prof. William B. Scott read a paper on "The Isthmus of Panama in its Relation to the Animals of North and South America."

The Judges of the Annual Election of Officers and Councillors, held on this day between the hours of two and five in the afternoon, reported that the following named members were elected to be the Officers for the ensuring year, according to the Laws, Regulations and Ordinances of the Society.

President.

William W. Keen.

Vice-Presidents.

William B. Scott,
Albert A. Michelson,
Edward C. Pickering.

Secretaries.

I. Minis Hays,
Arthur W. Goodspeed,
Amos P. Brown,
Harry F. Keller.

Curators.

Charles L. Doolittle,
William P. Wilson,
Leslie W. Miller.

Treasurer.

Henry La Barre Jayne.

Councillors.

(To serve for three years.)
Henry H. Donaldson,
Theodore W. Richards,
Robert A. Harper,
Edwin G. Conklin.

Special Meeting January 14, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

Dr. J. C. Bose, of Calcutta, read a paper on "The Control of Nervous Impulse in Plant and Animal."

Stated Meeting February 5, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

An invitation was received from the University of North Carolina to be represented at the Inauguration of Edward Kidder Graham, as President, at Chapel Hill, on the twenty-first of April.

A letter was received from Prof. Allen C. Thomas presenting his resignation of membership.

The decease was announced of the following members:

Benjamin Sharp, M.D., at Moorehead, N. C., on January 23, 1915; æt. 57.

Cyrus Fogg Brackett, A.B., LL.D., at Princeton on January 29, 1915; æt. 82.

The following papers were read:

"The Surgery of the Civil War as Contrasted with the Surgery of the Present European War," by W. W. Keen, M.D.

"The Antediluvian Patriarchs on a Tablet from Nippur," by George A. Barton, Ph.D., which was discussed by Professor Learned and Mrs. Stevenson.

Stated Meeting March 5, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

Dr. David Jayne Hill, elected to membership in 1910, subscribed the Laws and was admitted into the Society.

Letters were received:

From the President appointing Prof. W. LeConte Stevens to represent the Society at the inauguration of Edward Kidder Graham, as President of the University of North Carolina.

From Prof. W. LeConte Stevens, accepting the appointment.

The decease of the following members was announced:

Arthur vonAuwers, at Berlin on January 24, 1915.

James Geikie, LL.D., D.C.L., at Edinburgh, on March 2, 1915; æt. 75.

The following papers were read:

"The Swedes, Governor Printz, and the Beginning of Pennsylvania," by Thomas Willing Balch.

"A Missing Chapter in International History," by Hon. David Jayne Hill, which was discussed by Mr. Carson, Prof. Learned, and Mr. Rosengarten.

Stated Meeting April 9, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

An invitation was received from the Trustees and Faculty of Allegheny College, to be represented at the celebration of the One Hundredth Anniversary of the founding of the College, to be held at Meadville, Pa., in the week beginning the twentieth of June, 1915.

The decease of the following members was announced:

Charles Francis Adams, LL.D., at Washington on March 20, 1915; æt. 80.

Frederick Winslow Taylor, M.E., at Philadelphia on March 21, 1915; æt. 59.

David K. Tuttle, Ph.D., at Philadelphia on April 7, 1915; æt. 79.

Prof. Charles C. Bass read a paper on "Some Important Factors which Influence Asexual Reproduction of Malaria Plasmodia in Man," which was discussed by Dr. Tyson, Dr. Henry Skinner, Dr. McFarland, and Dr. Keen.

Stated General Meeting April 22, 23, and 24, 1915.

Thursday, April 22, 1915.

ALBERT A. MICHELSON, Ph.D., Sc.D., LL.D., F.R.S.,
Vice-President, in the Chair.

Prof. Eliakim H. Moore, elected to membership in 1905, and Prof. Robert Andrews Millikan, elected to membership in 1914, having subscribed the Laws, were admitted into the Society.

The following papers were read:

"Devices for Facilitating the Analysis of Observations—More Particularly those of the Tides," by Ernest W. Brown, Sc.D., Professor of Mathematics, Yale University.

"On Linear Integral Equations in General Analysis," by Eliakim H. Moore, Ph.D., Sc.D., LL.D., Head of Department of Mathematics, University of Chicago.

"A Direct Solution of Fredholm's Equation with Analytic Kernel," by Preston A. Lambert, Professor of Mathematics, Lehigh University, Bethlehem, Pa.

"The Existence of a Sub-Electron?" by Robert A. Millikan, Ph.D., Professor of Physics, University of Chicago, which was discussed by Prof. Michelson.

"Local Disturbances in a Magnetic Field," by Francis E. Nipher, A.M., LL.D., Professor of Physics, Washington University, St. Louis.

"Explorations over the Surface of Telephonic Diaphragms Vibrating under Simple Impressed Sounds," by A. E. Kennelly, S.D., A.M., Professor of Electrical Engineering, Harvard University and H. O. Taylor, of Cambridge

"The Hall and Corbino Effects," by Edwin Plimpton Adams, Professor of Physics, Princeton University. (Introduced by Prof. Magie.)

"Spontaneous Generation of Heat in Recently Hardened Steel," by Charles Francis Brush, Ph.D., Sc.D., LL.D., of Cleveland.

"Ruling and Performance of a Ten Inch Diffraction Grating," by A. A. Michelson, Ph.D., Sc.D., LL.D., Head of Department of Physics, University of Chicago.

Friday, April 23.

Morning Session—9.35 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

The following papers were read:

"Heredity in Protozoa," by M. H. Jacobs, Ph.D., Assistant Professor of Zoölogy, University of Pennsylvania. (Introduced by Prof. McClung.)

"The Constitution of the Hereditary Material," by T. H. Morgan, Ph.D., Professor of Experimental Zoölogy, Columbia University, New York. (Introduced by Prof. E. G. Conklin.) Discussed by Prof. Conklin.

"The Problem of Adaptation as Illustrated by the Fur Seals of the Pribilof Islands" (illustrated by lantern slides), by George H. Parker, Sc.D., Professor of Zoölogy, Harvard University. Discussed by Professors Conklin and Cattell.

"An Interpretation of Sterility in Hybrids," by Edward M. East, Ph.D., Professor of Experimental Plant Morphology, Harvard University. (Introduced by Prof. Bradley Moore Davis.)

"Heterosis and the Effects of Inbreeding," by George H. Shull, Ph.D., Botanical Investigator, Station for Experimental Evolution, Carnegie Institution. (Introduced by Prof. Bradley M. Davis.)

"The Significance of Sterility in Œnothera," by Bradley M. Davis, Ph.D., Professor of Botany, University of Pennsylvania.

The preceding three papers were discussed by Prof. Parker.

"Morphology and Development of Agaricus rodmani," by George F. Atkinson, Ph.D., Head of Department of Botany, Cornell University.

"The Large-fruited American Oaks," by William Trelease, Sc.D., LL.D., Professor of Botany, University of Illinois, Urbana.

"Relationships of the White Oaks of Eastern North America," by M. V. Cobb. (Introduced by Prof. Trelease.)

"The Present Need in Systematic Botany," by L. H. Bailey, LL.D., late Director of the College of Agriculture, Cornell University.

Afternoon Session—2 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

The following papers were read:

"A Convenient Form of Receiver for Fractional Distillations under Diminished Pressure,'" by Marston T. Bogert, LL.D., Professor of Chemistry, Columbia University, New York.

"The Cymene Carboxylic Acids," by J. R. Tuttle and Marston T. Bogert, of Columbia University, New York.

"Syringic Acid and its Derivatives," by E. Plaut and Marston T. Bogert, of Columbia University, New York.

The three preceding papers were discussed by Profs. Keller and Scott.

"The Relation of Ductless Glands to Dentition and Ossification," by William J. Gies, Ph.D., Professor of Biological Chemistry, Columbia University. (Introduced by Prof. Harry F. Keller.)

"Gastro-Intestinal Studies," by Philip B. Hawk, Ph.D., Professor of Physiological Chemistry and Toxicology, Jefferson Medical College, Philadelphia. (Introduced by Dr. W. W. Keen.) Discussed by Prof. Scott.

"On the Rate of Evaporation of Ether from Oils and its Application in Oil-Ether Colonic Anæsthesia," by Charles Baskerville, Ph.D., Professor of Chemistry, College of the

City of New York. (Introduced by Prof. J. P. Remington.) Discussed by Profs. Scott and Remington.

"On Oral Endamebiosis," by Allen J. Smith, M.D., Sc.D., LL.D., Professor of Pathology, University of Pennsylvania. Discussed by Prof. Bogert.

"Certain Factors Conditioning Nervous Responses," by Stewart Paton, M.D., Lecturer in Biology, Princeton University. Discussed by Profs. Donaldson and Scott.

"The Rights and Obligations as to Neutralized Territory," by Charlemagne Tower, LL.D., of Philadelphia.

"Physiographic Features as a Factor in the European War," by Douglas W. Johnson, Ph.D., Associate Professor of Physiography, Columbia University. (Introduced by Mr. Henry G. Bryant.)

"The Pronouns and Verbs in Sumerian," by J. Dyneley Prince, Ph.D., Professor of Semitic Languages, Columbia University, New York. (Read by title.)

"A New Form of Nephelometer," by J. T. W. Marshall, Harriman Research Laboratory, Roosevelt Hospital, New York.

Dr. Stewart Paton a newly-elected member and the Hon. Simeon E. Baldwin, elected to membership in 1910, subscribed the Laws and were admitted into the Society.

Friday Evening—8.15 o'clock.

William Morris Davis, Sc.D., Ph.D., Professor Emeritus of Geology, Harvard University, gave an illustrated lecture, "On New Evidence for Darwin's Theory of Coral Reefs." A statement of the chief results of a Shaler Memorial Voyage across the Pacific in 1914, with Studies of the Fiji Group, New Caledonia, the Loyalty Islands, the New Hebrides, the Great Barrier Reef of Australia and the Society Islands.

Saturday, April 24.

Executive Session—9.30 A.M.

William W. Keen, M.D., LL.D., President, in the Chair.

Pending nominations for membership were read and spoken to.

Dr. L. A. Bauer and Secretary Brown were appointed tellers of election and the Society proceeded to ballot for members.

The tellers reported that the following nominees had been elected to membership:

Residents of the United States.

John J. Abel, M.D., Baltimore, Md.
Edwin Plimpton Adams, Ph.D., Princeton, N. J.
Walter Sydney Adams, Pasadena, Cal.
John Merle Coulter, Ph.D., Chicago, Ill.
Whitman Cross, Ph.D., Washington, D. C.
William J. Gies, M.D., New York City.
Philip Bovier Hawk, Ph.D., Philadelphia.
John Fillmore Hayford, Evanston, Ill.
Emory Richard Johnson, Sc.D., Philadelphia.
John Anthony Miller, Ph.D., Swarthmore, Pa.
Thomas Hunt Morgan, Ph.D., New York.
William Fogg Osgood, Ph.D., Cambridge, Mass.
Raymond Pearl, Ph.D., Orono, Me.
Theobald Smith, M.D., Boston, Mass.
John Zeleny, Ph.D., Minneapolis, Minn.

Morning Session—10 o'clock.

William B. Scott, Sc.D., LL.D., Vice-President, in the Chair.

The following papers were read:

"Opium in the Bible," by Paul Haupt, Ph.D., Professor of Semitic Languages, Johns Hopkins University, Baltimore.

"Divisions of the Pleistocene of Europe and the Periods of the Entrance of Human Races," by Henry Fairfield Osborn, Sc.D., LL.D., Research Professor of Zoölogy, Columbia University, N. Y.

"The Occurrence of Algæ in Carbonaceous Deposits," by Charles A. Davis, Ph.D., of U. S. Bureau of Mines. (Introduced by Prof. Marston T. Bogert.) Discussed by Profs. Scott and B. M. Davis.

"Additions to the Fauna of the Lower Pliocene Snake Creek Beds, Nebraska," by W. J. Sinclair, Ph.D., Curator of Vertebrate Paleontology, Princeton University. (Introduced by Prof. W. B. Scott.) Discussed by Prof. Scott.

"Tertiary Vertebrate Faunas of the North Coalinga Region of California," by John C. Merriam, Ph.D., Professor of Paleontology and Historical Geology, University of California.

"The Rôle of the Glacial Anticyclone in the Air Circulation of the Globe," by William H. Hobbs, Ph.D., Professor of Geology, University of Michigan.

"Note on the Sun's Temperature," by Henry Norris Russell, Ph.D., Professor of Astronomy, Princeton University.

"Radial Velocities in the Orion Nebula," by Edwin B. Frost, D.Sc., Director of Yerkes Observatory, Williams Bay, Wis. Discussed by Prof. Russell.

"Some Results from the Observation of Eclipsing Variables," by Raymond S. Dugan, Assistant Professor of Astronomy, Princeton University. (Introduced by Prof. H. N. Russell.)

"The Variable Stars TV, TW, and TX Cassiopeiæ," by R. J. McDiarmid, Fellow, Princeton University. (Introduced by Prof. H. N. Russell.)

"The Euler-Laplace Theorem on the Rounding Up of the Orbits of the Heavenly Bodies under the Secular Action of a Resisting Medium," by T. J. J. See, Ph.D., U. S. Naval Observatory, Mare Island, Cal.

"The Work in Atmospheric Electricity aboard the 'Carnegie,'" by L. A. Bauer, Ph.D., D.Sc., Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and W. F. G. Swann, D.Sc.

"Tammuz and Osiris," by George A. Barton, Ph.D., Prof. of Biblical Literature and Semitic Languages, Bryn Mawr College, which was discussed by Dr. Jastrow.

Afternoon Session— 2 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Dr. John Fillmore Hayford, a newly elected member, subscribed the Laws and was admitted into the Society.

A portrait of Dr. Edgar F. Smith, of Philadelphia, was presented to the Society by Dr. J. H. Penniman on behalf of the donor.

The following papers were read:

"One Dimensional Gases and the Reflection of Molecules from Solid Walls."

"Recent Progress in the Study of the Iodine Resonance Spectra, with a description of a Long Focus Spectroscope of High Power," by Robert Williams Wood, A.B., LL.D., Professor of Experimental Physics, Johns Hopkins University. Discussed by Dr. Brush, Prof. Noyes and Dr. Webster.

Symposium on the Earth: Its Figure, Dimensions and the Constitution of Its Interior

"From the Astronomical Standpoint," by Frank Schlesinger, Ph.D., Director of Allegheny Observatory, Pittsburgh.

"From the Geological Standpoint," by T. C. Chamberlin, Ph.D., LL.D., Head of Department of Geology, University of Chicago.

"From the Seismological Standpoint," by Harry Fielding Reid, Ph.D., Professor of Dynamical Geology and Geography, Johns Hopkins University, Baltimore.

"From the Geophysical Standpoint," by John F. Hayford, Director of College of Engineering, Northwestern University, Evanston, Ill. (Introduced by Prof. Schlesinger.)

These papers were discussed by Professors H. F. Reid, Arthur G. Webster, E. W. Brown, C. L. Doolittle, Frank Schlesinger and W. H. Hobbs.

Stated Meeting May 7, 1915.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Letters accepting membership were received from:

John J. Abel, M.D., Baltimore, Md.
Edwin Plimpton Adams, Ph.D., Princeton, N. J.
John Merle Coulter, Ph.D., Chicago, Ill.
Whitman Cross, Ph.D., Washington, D. C.
William J. Gies, M.D., New York City.
Philip Bovier Hawk, Ph.D., Philadelphia.
Emory Richard Johnson, Sc.D., Philadelphia.
John Anthony Miller, Ph.D., Swarthmore, Pa.

Thomas Hunt Morgan, Ph.D., New York.

Raymond Pearl, Ph.D., Orono, Me.

Theobald Smith, M.D., Boston, Mass.

An invitation was received from the Johns Hopkins University to be represented at the Inauguration of Frank Johnson Goodnow, as President, on May 20, 1915.

The following papers were read:

"Oil Concentration of Ores," by Howard W. DuBois, M.E. (Introduced by Dr. Harry F. Keller.) Discussed by Mr. Lehman.

"Concretions in Streams Formed by the Agency of the Blue-Green Algæ and Related Plants," by H. Justin Roddy, M.S. (Introduced by the Secertaries.) Discussed by Dr. Harshberger, Mr. Sanders, and Prof. Keller.

"The Conditions of Black Shale Deposition as illustrated by the Kupferschiefer and Lias of Germany," by Charles Schuchert.

Stated Meeting October 1, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

Professors Philip B. Hawk, Emory R. Johnson, and John Anthony Miller, newly-elected members, subscribed the Laws and were admitted into the Society.

Letters accepting election to membership were received from

Prof. Walter S. Adams.

Prof. John F. Hayford.

Prof. William F. Osgood.

Prof. John Zeleny.

Invitations were received:

From the Secretary of State to participate in the Second Pan-American Scientific Congress to be held under the auspices of the Government of the United States, at the city of Washington from December 27, 1915, to January 8, 1916.

From the Trustees and Faculty of Vassar College, to be represented at the celebration of the Fiftieth Anniversary of the opening of Vassar College during the week beginning October 10, 1915.

The decease of the following members was announced:

Mr. Samuel Dickson, at Philadelphia, on May 28, 1915, æt. 78.

Hon. James T. Mitchell, at Philadelphia, on July 4, 1915, æt. 81.

Mr. Frederick Prime, at Atlantic City, on July 14, 1915, æt. 69.

Sir James A. H. Murray, at Oxford, England, on July 26, 1915, æt. 78.

Prof. Frederick W. Putnam, at Cambridge, Mass., on August 14, 1915, æt. 76.

Mr. John T. Morris, at Bretton Woods, N. H., on August 15, 1915, æt. 67.

Dr. Austin Flint, at New York, on September 22, 1915, æt. 79.

The following papers were read:

"Timber Studies in the Mississippi Bottom Lands," by Henry C. Cowles, Ph.D., of Chicago, which was discussed by Professors Harshberger and Kraemer.

"A Practical Rational Alphabet," by Benjamin Smith Lyman, A.B.

Stated Meeting November 5, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

Prof. Ulric Dahlgren read a paper on "The Production of Heat by Animals."

Stated Meeting December 3, 1915.

William W. Keen, M.D., LL.D., President, in the Chair.

An invitation was received from the American Association for the Advancement of Science to send one or more delegates to its meeting to be held at Columbus, Ohio, December 27, 1915, to January 1, 1916.

Mr. H. H. Harjes, in accordance with the expressed direction of his father, the late John H. Harjes, of Paris, transmitted to the Society Dr. Franklin's bamboo cane with a horn handle, in the upper hollow chamber of which he was accustomed to carry oil and from it in his walks he dropped oil upon the water to watch its effect upon wind-beaten pools.

The decease was announced of William Brooke Rawle, A.B., at Philadelphia, on November 30, 1915, æt. 72.

The following papers were read:

"Some of the Neuro-retinal Interpretations of Increased Vascular and Increased Intracranial Pressure, being a Clinical Communication," by Dr. George E. deSchweinitz.

"The Geology of Parahyba and Rio Grande do Norte, Brazil," by Ralph H. Soper, communicated by Prof. John C. Branner.

"The Geology of Ceará and Piauhy, Brazil," by H. L. Small, communicated by Prof. John C. Branner.

Dr. W. W. Keen presented the Annual Address of the President.

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